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JOURNAL

OF THE

INSTITUTION OF ELECTRICAL ENGINEERS,

INCLUDING

IGINAL COMMUNICATIONS ON TELEGRAPHY AND ELECTRICAL SCIENCE.

BLISHED UNDER THE SUPERVISION OF THE EDITING COMMITTEE,

AND EDITED BY

W. G. McMILLAN, SECRETARY.

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TABLE OF CONTENTS.

VOL. XXIX.

[redacted]

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

Vol. XXIX. 1899. No. 142.

The Three Hundred and Thirty-Fifth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday evening, November 16th, 1899—Mr. J. W. Swan, F.R.S., Ex-President, in the Chair.

The minutes of the Ordinary General Meeting held on May 25th were read and approved.

The names of new candidates for election into the Institution were announced and ordered to be suspended.

The following transfers were announced as having been approved by the Council, viz. :—

From the class of Associates to that of Members—

Harry Otto F. Bindemann.
John Richard Bainton.
W. S. Furby.
Robert Edward Pemberton Pigott.

From the class of Associates to that of Associate Members—

Herbert James Allen.
Howard S. Baker.
Thomas Gooch Aldrich.
Russell Allport.
Thomas Dawson Clothier.
James Edgar.
Edmund John Fox.
David J. Gadsby.
Walter Hibbert.
A. B. Layton.
W. M. L'Estrange.
William Lund.
A. E. Mayes.
Ernest Mercer.
E. A. Mitchell.
Arthur Patrick O'Brien.
Arthur P. Patey.
Samuel Rignold Pedroza.
Alfred Lovell Phillips.
Thomas Rungay.
Henry Mannington Sayers.
Harry E. Stobie.
W. B. Winfield.
George Herbert Wyatt.
Victor Zingler.

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From the class of Students to that of Associates—

Edward George Brown.
Arthur F. R. Curteis.
Leopold J. Harris.
Robert Alexander D. Macalister.
Bertrice L. Roberts.

Donations to the Library were announced as having been received since the last meeting from—

Mr. Charles Aburrow, The Astronomer Royal, M. Omer de Bast, M. Gustavo D'Orso, Messrs. Gauthier Villars et Fils, Mr. J. Graham, The Institution of Mechanical Engineers, Mr. W. J. Hammer, Mr. W. H. Lindley, Mr. D. R. Walker; and from Mr. Charles Bright, Mr. J. J. Fahie, Mr. W. Perren Maycock, Mr. J. Clifton Robinson, Sir Charles Todd, Mr. A. P. Trotter, Mr. C. H. Wordingham, Members; Mr. F. Bathurst, Associate Member; Mr. B. Tamaki, Foreign Member; and Mr. W. G. McMillan, Associate.

To all of whom, on the motion of the PRESIDENT, a vote of thanks was unanimously accorded.

The SECRETARY read the following letter from the Home Secretary:—

"HOME OFFICE, WHITEHALL, *June* 14, 1899.

"SIR,—I have had the honour to lay before the Queen the Address conveying to Her Majesty the congratulations of the Institution of Electrical Engineers on the occasion of her Eightieth Birthday, which Address Her Majesty was pleased to receive very graciously.

"I have the honour to be,
"Your obedient servant,
"M. W. RIDLEY.

"The Secretary to the Institution of Electrical Engineers, Victoria Mansions, 28, Victoria Street, S.W."

The SECRETARY read the following letter from Colonel Huber:—

"ZURICH, *October* 26, 1899.

"*To the President and Members of the Institution of Electrical Engineers, London.*

"GENTLEMEN,—On your visit to Switzerland and its electrical industries in September last, you were kind enough, before you left Zürich, to present me a most valuable album containing the portraits of the Presidents of your honourable Institution, and the signatures of the members present in Zürich.

"I am indeed very proud of such a token of your esteem, and I have the greatest pleasure in thinking that what little we could show you in our small country has been of interest to you and has given you

some satisfaction. I return you my sincerest thanks for this rare present, and shall always consider it as a precious remembrance of the visit by which your illustrious Institution honoured the electrical industry and science of my country.

"I regretted, more than I can describe, my having been prevented both welcoming you on your visit to Switzerland, and from receiving the kind present from your dear President personally.

"Having now recovered satisfactorily, I hasten to repeat my thanks, which my son has already expressed you, both for the album and for your visit in general.

"With my sincerest wishes for the further prosperity of the Institution of Electrical Engineers,

"I am most sincerely yours,

"G. E. HUBER."

The CHAIRMAN (Mr. J. W. Swan): It seems to belong to this part of our proceedings to make the announcement that last week the Council received the following letter from our Honorary Member, Mr. Henry Wilde, F.R.S., announcing his offer of the sum of £1,500 for investment as a Benevolent Fund for the benefit of members of the Institution, with observations on the evolution of the dynamo-electric machine:—

"ALDERLEY EDGE, CHESHIRE,
November 2, 1898.

"*To the Council of the Institution of Electrical Engineers.*

"Last year, by the favour of the Council, I was elected an Honorary Member of the Institution of Electrical Engineers. The exceptional character of this honour was duly appreciated by me, and I naturally concluded that the distinction had been conferred from a fair knowledge of my contributions to electrical science, both pure and applied. I notice, however, that one of the members of the Council (Prof. J. A. Ewing, F.R.S.), in the course of his recent James Forrest Lecture on Magnetism, delivered before the Institution of Civil Engineers, has made mention of my name and work in connexion therewith in such a manner as to require some justification in the eyes of the general body of the members of the Institution for the honour the Council have done me. I have, therefore, thought it desirable, though at the risk of incurring the imputation of egotism, to set forth in order a brief record of my work in connexion with magnetical and electrical science, both for

the satisfaction of the Council and as a duty which I owe to my own reputation.

"Your Honorary Member commenced his career as a mechanical engineer under a regular apprenticeship, and, through his inventive ability and other qualities, was placed in a responsible and lucrative position by the firm where he was employed, before attaining his majority. From his youth he has had a strong predilection for the natural sciences—the construction of electrical machines, voltaic batteries, electrotyping cells, electric kites, and other scientific apparatus being the interests and amusements of his leisure hours.

"In 1856 your Honorary Member commenced to practise on his own account as a telegraph and lightning-conductor engineer, and took out his first patent in connexion with these branches of applied electricity in 1858. It was during the course of his wide practice as a lightning-conductor engineer that he observed the influence of gas- and water-pipes in determining the direction of a discharge of lightning and the danger from fire and other damage arising therefrom. He also adopted the necessary means for averting this danger by connecting the lightning-conductor with the gas or water mains, and subsequently published an account of his observations in the *Philosophical Magazine*, 1872. His recommendations have since been adopted by the Lightning Rod Conference (1882), and by other scientific committees abroad which have investigated the subject.

"During the years 1861–1863 your Honorary Member took out several patents for his inventions connected with the magneto-electric alphabetic telegraph, and ultimately succeeded in producing an instrument which compared favourably with all others of the like class in the rapidity and facility with which messages could be transmitted. To carry out his telegraph inventions he found it necessary to obtain a special Act of Parliament under the powers of the General Act of 1862. This special Act was the first and only Act granted until the acquisition of the telegraphs by the Government in 1870.

"During the course of his experiments with the later form of his telegraph instruments, your Honorary Member observed the great increase of power of an electro-magnet

above that of the permanent magnets of the magneto-electric machine which excited it. This observation led him up to the discovery of the principle and invention of the *dynamo*, as the machine is now called.[1] The invention is described and figured in the specifications of his patents of December, 1863, and October, 1865. Her Majesty's Privy Council granted your Honorary Member an extension of these patents from fourteen to twenty-one years.

"In a paper which was read before the Royal Society in April, 1866, your Honorary Member formulated the proposition that quantities of magnetism and electricity indefinitely small will induce quantities of these forces indefinitely great. The proposition was demonstrated by experiments on a large scale in which a powerful electric light was evolved for the first time from a dynamo machine (*Proc. Roy. Soc.*, April, 1866; *Phil. Trans.*, 1867). It was reserved for the Executive Council of the International Inventions Exhibition, London, 1885, to award your Honorary Member a medal of honour for his discovery, in the terms of the proposition formulated in his paper, although not an exhibitor.

"It was subsequently found by several electricians that the residual or permanent magnetism of iron could be used as the initial stage of the indefinite increase of the magnetism of a dynamo by the simple device of coupling up, directly, the electro-magnet and armature circuits of the original dynamo described by your Honorary Member without any change whatever in its construction or in the principle on which it is based. This device, valuable as it has since been found in practice, had, however, the disadvantage of the resultant current being in one direction only, while the separately excited dynamos produced alternating or direct currents of different orders as required, without altering the windings of the field magnets. Moreover, by reason of the residual or permanent magnetism of his large dynamo being many times greater than that of the small steel magnets of the magneto-electric machine which excited it, the general principle of indefinite magnetic

[1] Science owes the invention of the term *Dynamo-electric Machine* to Charles Brooke, F.R.S., who applied it expressly to Wilde's Electro-magnetic Generator. (*Proc. Roy. Soc.*, vol. xv. (1867) p. 409.)—H. W.

accumulation, as formulated and demonstrated by your Honorary Member, is common to every class of dynamo machine.

"In 1868 your Honorary Member discovered the property of the alternating current to control and render synchronous the rotations of a number of dynamos, by which their united power can be obtained without the use of mechanical gearing and independently of the relative position and distance of the separate dynamos from each other. This property of the alternating current was fully described by him, with its advantages, in a paper read before the Manchester Literary and Philosophical Society, and published in its *Proceedings*. Also in the *Philosophical Magazine*, January, 1869; *The Engineer*, vol. xxvii. (1869) p. 252; *Annales de Chimie et de Physique*, vol. xvi. (1869) p. 487. The synchronism of a pair of small magneto-electric machines was also exhibited at a soirée of the Royal Society in the same year. This property of the current is an essential feature in the combination of alternating dynamos at Niagara, Geneva, and other central distributing stations.

"In the course of a lecture delivered before the Institution of Civil Engineers in 1883, the late Dr. John Hopkinson brought forward the synchronous rotation of alternating dynamos as a theoretical prevision of his own, but, on his attention being directed to the prior publication of the discovery, he acknowledged the reclamation in subsequent papers. Nevertheless, the ill-advised friends of Dr. Hopkinson, notably Prof. J. A. Ewing (*Proc. Roy. Soc.*, vol. lxiv., February, 1899), have again brought forward this belated prevision, with full knowledge, but without mention, that the discovery had been made experimentally and published some years previously. Your Honorary Member now thinks it well to state that an account of the synchronous rotation of alternating dynamos was written by himself for Stevenson's *Lighthouse Illumination*, 2nd edition (1871), p. 165. In the preface to this standard work on Lighthouse Optics, the author expresses his obligations for many valuable suggestions made by his friend Mr. James T. Chance, the head of the firm where Dr. Hopkinson was employed for some years as an expert in Lighthouse Optics. Now, it would be a reflection on the intelligence and industry of the late Dr. Hopkinson to

suppose that he had not carefully studied the important work of Stevenson, consisting, as it does, of only 236 pages. It is, therefore, much more probable that the idea of the synchronous rotation of alternators was drawn unconsciously from Dr. Hopkinson's memory than from the inspiration of his genius.

"In March, 1867, your Honorary Member invented and patented the multipolar alternating dynamo, both self and separately excited. This dynamo, with the mode of exciting it, is the type of all the large alternators employed at Niagara, Geneva, and other places. The great hydro-electric installation at Niagara is a complete embodiment of the discoveries and inventions of your Honorary Member in connexion with the generation of electricity, as—(1) It is based on the principle of the indefinite increase of the magnetic and electric forces from quantities indefinitely small; (2) the field magnets of the dynamos are excited by the currents from separate dynamo machines in accordance with the specifications and claims of his patents of 1865 and 1867; (3) the alternators are multipolar, excited by a separate dynamo as described and claimed in his patent of March, 1867; and (4) the synchronising property of the alternating current is utilised to obtain the united power of a number of dynamos without the use of mechanical gearing.

"The first practical application of the dynamo to the arts of life was made directly by your Honorary Member to the electro-deposition of metals from their solutions (1867–80); his dynamos, both in their two polar and self-exciting multipolar forms, soon superseding the voltaic battery in the principal electro-plating and electro-typing establishments in this country and abroad. They were also largely employed (1868) in the electrolytic process of refining copper invented by Mr. James B. Elkington, and for the like purpose by the Mansfeld Mining Company, Saxony (1873). Your Honorary Member has since shown that the principle underlying the electrolytic process of refining copper, and on which its commercial success depends, is the indefinite increase of the electro-chemical forces from quantities indefinitely small, as the current from a single voltaic cell will electrolyse copper-sulphate solutions in an indefinite series of electrolytic cells (*Manchester Memoirs*, vol. xl., 1896).

"In 1875–76 your Honorary Member succeeded for the

first time in electro-coating large iron cylinders with an adhesive layer of homogeneous copper, suitable for engraving upon and for other purposes. The process formed the subject of two of his patents, and has now become a considerable industry.

"From 1873 to 1880 your Honorary Member adapted his self-exciting multipolar dynamos to the production of the search-light in the Royal Navy; his hand electric-light regulator, patented in 1873 and now in universal use, forming part of the equipment. After lengthened trials at Spithead by a joint War Office and Admiralty Committee, his search-light was adopted, and a number of first-class battleships were equipped with it under his direction. Annexed is a copy of a report of the Admiral commanding the Channel Squadron on the search-light established on H.M.S. *Minotaur*, 1875.

"In the foregoing review of his own inventions and contributions to knowledge connected with the evolution of electricity and magnetism, your Honorary Member is not unmindful of the important improvements that have been made subsequently by other inventors in the same field. He would specially mention, as the most prominent of these improvements, (*a*) the utilisation of the residual magnetism of iron as the initial stage of the excitation of the field magnets of dynamos; (*b*) the production of continuous currents from dynamos, as distinguished from alternating waves of electricity; (*c*) the compounding of dynamos for the automatic regulation of the quantity of electricity generated to the amount required in the external circuit; (*d*) the subdivision of the iron of the armatures, and the improved forms and proportions of the several parts of dynamos, whereby their efficiency in relation to the expenditure of mechanical power, with economy of material, has been greatly increased.

"On the expiration of the several patents for his inventions and the extensions thereof, 1884, your Honorary Member retired from the pursuit of the practical applications of electricity, but he continues to maintain his interest in several branches of scientific research.

"During the years 1885–90 he was engaged in an experimental investigation of the causes of terrestrial magnetism, and, by his invention of the Magnetarium, he has succeeded

in reproducing all the principal phenomena of the earth's magnetism and the secular changes in its horizontal and vertical components for long periods of time. He has also demonstrated on the magnetarium that the short range and period of westerly declination at London (24°—160 years), the long range and period of westerly declination at the Cape of Good Hope (30°—272 years), and the rapid change of the dip in the Gulf of Guinea (17 minutes annually) are electro-geometrically correlated. He has further shown that the unsymmetrical distribution of the earth's magnetism as shown on the charts is due principally to the unequal magnetic intensity of the land and ocean areas respectively (*Proc. Roy. Soc.*, 1890, 1891, 1894). Examples of his magnetarium, dynamos, and telegraph instruments have been deposited in the National Museum of Inventions and Scientific Instruments at South Kensington.

"In 1890 your Honorary Member made a series of experiments on the influence of temperature on the magnetisation of iron and other magnetic substances. He showed that the increase of the magnetic power of red-hot iron observed by other experimenters is only apparent and so small in amount that it cannot be detected by the method of traction, and is a negligible quantity in electrical engineering. The anomalous increase was found to be due to the screening action of the external parts of the iron when cold, as the magnetic needle indicated an increase or decrease of magnetic power according as the mass of the same iron submitted to its action was greater or smaller (*Proc. Roy. Soc.*, 1891). Your Honorary Member has designed a Magnetometer, for showing the influence of temperature on the magnetisation of iron and other magnetic substances, described in the *Manchester Memoirs*, 1895, and also in the *Electrical Review*.

"He has also determined the magnetisation limit of iron at normal temperatures by the single-pole method of traction described by him in his paper on the influence of heat on the magnetic power of this metal. His experiments show a magnetisation limit for iron of 422 lbs. per square inch of section, or 29·67 kilos per sq. cm. (*Proc. Roy. Soc.*, vol. lxi., 1897).

"Lastly, in view of the various uses to which your Honorary Member endeavoured to apply his electrical

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so far he has not taken the chair as President at an Ordinary General Meeting at the beginning of a session. The question arose whether, under the new state of things, seeing that the Ex-President had been so long out of office, it was proper to retain the old practice of his formally inducting the new President into the Chair. It was referred to the President, and he decided that it was desirable to retain the ancient procedure. Therefore it is that I am here to-night in the place I have occupied so often, and with so much pleasure. But I am only brought back to official life for the moment in order to perform a final act, and that a most agreeable one, viz., to introduce my successor, and to bespeak for him all the considerate kindness you have shown to me.

With very great pleasure I now give place to Dr. Thompson, confident that the interests of the Institution will be well cared for during his tenure of office, and that the work will be continued under conditions that will ensure not merely the maintenance but the increase of the prestige and prosperity of the Institution.

Dr. SILVANUS THOMPSON, F.R.S., then took the Presidential Chair, vacated by Mr. Swan.

Sir HENRY MANCE: It is my privilege, in accordance with a time-honoured custom, to ask you to place on record your thanks to the Past-President for his services. I therefore beg to propose the following resolution :—"That the cordial thanks of the members of the Institution of Electrical Engineers be offered to Mr. Swan for the admirable manner in which he has filled the position of President during his seventeen months of office, and for the unremitting zeal and care which he has devoted to the interests of the Institution and the duties of his office."

I am sure that this is a resolution which you will pass with acclamation. Mr. Swan, as the resolution states, has been in office for a much longer time than any of our previous presidents, and during the period he has occupied the chair his work has been of exceptional importance in consequence of the formulating and passing of the new rules, which eventually will tend greatly to the advantage of the Institution.

I am sure every member of Council will support me in acknowledging the tact and suavity with which Mr. Swan

has performed the duties of President. His name is "familiar in our mouths as household words," and every member must feel proud that we shall enrol on our list of Past-Presidents the name of one who has done so much for Electrical Engineering.

I think I may safely say that no one more appreciates the honour of being President of this Institution than Mr. Swan himself, but I think you will agree with me that if the Institution has done honour to him, Mr. Swan has done honour to the Institution.

Mr. ALEXANDER SIEMENS: Your applause really makes it quite superfluous that this motion should be seconded, but although Sir Henry Mance has very aptly spoken of the recent achievements of Mr. Swan, we should not forget his original achievement which he accomplished for himself without any help, viz., the solution of the distribution of electricity at a time when, if I may say so, the regular electricians were all on by-paths. I take the liberty of saying that because I was among the number, at least I followed in the footsteps, of some who looked for the distribution of electricity in the wrong direction. That original merit of Mr. Swan, that he worked out such a difficult problem entirely by himself and through his own studies ought not to be forgotten. Now that he has added the merit of having conducted our Institution for seventeen months, double thanks are due to him, and I have great pleasure in seconding the motion.

The vote was carried by acclamation.

Mr. J. W. SWAN: I should be made of very insensible material if I did not feel intensely the kindness expressed in your vote. I wish to thank separately Sir Henry Mance for the very kind things he said of me, and also my friend Mr. Alexander Siemens. Sir Henry Mance very rightly said that I must have felt it an honour to be President of this great Institution. I have felt it to be a great honour, and it has been a source of satisfaction and pleasure to me that during my tenure of office the affairs of the Institution have gone very well. The revenue has increased, and the membership has increased, but I entirely disclaim any credit in bringing that state of things about. It was due in part to external circumstances, but very largely to the most laborious and *efficient support I* received from an

some of this waste; and it might do much more without imposing any harmful restrictions upon the freedom of a single individual. If it can point out the trend of opinion, the ameliorations resulting from experience in all parts of the world; if it can help to diffuse amongst its membership generally a knowledge of these things and of the latest discoveries and inventions, the benefit it will confer not only on its members, but on the industry at large, will be no small one.

I therefore propose to direct your attention to some of the tendencies which manifest themselves at present in the electrical world; some of them, doubtless, transitory, but others indicating changes of a permanent kind.

In telegraphy, the oldest branch of our profession, there is not much room to chronicle change. Nevertheless there is an obvious tendency to increased use of automatic methods of sending. Slowly but surely the use of the automatic transmitter is extending in cable service; whilst on the Continent and in America the advantages of the Wheatstone automatic are being gradually recognised, as the increase of matter to be transmitted over existing land lines causes a demand for accelerated methods. It may be here recalled that the very first paper read before this Institution on March 13, 1872, when it commenced operations as the Society of Telegraph Engineers, was on the topic of Automatic Transmission. The use of alternating currents of a fairly high frequency is also receiving attention. Professor Rowland has invented a multiplex typewriter working with alternate currents. The substitution of delicate optical receivers, working by photography for the purpose of enabling more rapid signals to be received, for the relays and recorders previously used, opens out a further field. Just as the limit at which the hand can send is surpassed by the automatic sender, so the speed at which the eye can read the visible motion is surpassed by that of the photographic receiver. In this connection the recent suggestions on the one hand of Squier and Crehore, and on the other of Pollak and Viràg, demand careful attention. The experiments of the latter between Buda Pesth and Berlin appear to have come as a surprise to many Continental electricians not previously conversant with the Wheatstone automatic transmitter; while the suc-

cess that they have obtained in sending words at the rate of 1,300 to 1,500 words per minute over a land line 475 miles long once more raises the familiar question whether a mile or two of subterranean cable inserted in the line would not have effectually barred the transmission and reduced it to ordinary rates. We need not believe all the nonsense telegraphed by special correspondents to the daily press from Vienna, that home of scientific canards. But Pollak and Viràg's results are of more substance than the imaginary achievements of Jan Szczepanik. It is interesting to note that in their experiments success was largely due to the use at each end of the line of an inductive shunt—a device advocated so strongly for cables by our late Past President, Mr. Willoughby Smith.

When we turn to the question whether such rapid methods of signalling will prove of any use on subterranean or submarine cables, we are still confronted by the old difficulty that no improvements whatever in apparatus at the ends of the cable will get rid of the sluggishness inherent in the cable itself, if constructed upon the traditional patterns. The suggestion which I advocated in 1893 of accelerating the speed of signalling by attacking the problem in the middle instead of tinkering at the ends has not yet borne fruit. My suggestion to construct cables with a series of self-inductive artificial leaks of high resistance distributed all along its length to combat its distributive capacity appears to be too radical to be acceptable to the cable authorities. But it is self-evident that whatever good an inductive shunt (or artificial "leak") at the end of a cable will do in getting rid of the static charges, an inductive shunt (or artificial inductive "leak") at the middle will do just twice as much. Why, then, should the suggestion to utilise this known property at one or more points along the length of the cable not be put to an experimental trial?

Of the tendencies in the telephonic world I forbear to speak. Great Britain has little reason to be proud of her record—past and present—in that line. She allowed the microphone, freely given to the world by its too generous inventor, to be exploited as a monopoly by others.

The competition of electricity with gas as a means of illumination has been rendered very severe by the improvements introduced *during recent years* in incandescent gas

some of this waste; and it might do much more without imposing any harmful restrictions upon the freedom of a single individual. If it can point out the trend of opinion, the ameliorations resulting from experience in all parts of the world; if it can help to diffuse amongst its membership generally a knowledge of these things and of the latest discoveries and inventions, the benefit it will confer not only on its members, but on the industry at large, will be no small one.

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In telegraphy, the oldest branch of our profession, there is not much room to chronicle change. Nevertheless there is an obvious tendency to increased use of automatic methods of sending. Slowly but surely the use of the automatic transmitter is extending in cable service; whilst on the Continent and in America the advantages of the Wheatstone automatic are being gradually recognised, as the increase of matter to be transmitted over existing land lines causes a demand for accelerated methods. It may be here recalled that the very first paper read before this Institution on March 13, 1872, when it commenced operations as the Society of Telegraph Engineers, was on the topic of Automatic Transmission. The use of alternating currents of a fairly high frequency is also receiving attention. Professor Rowland has invented a multiplex typewriter working with alternate currents. The substitution of delicate optical receivers, working by photography for the purpose of enabling more rapid signals to be received, for the relays and recorders previously used, opens out a further field. Just as the limit at which the hand can send is surpassed by the automatic sender, so the speed at which the eye can read the visible motion is surpassed by that of the photographic receiver. In this connection the recent suggestions on the one hand of Squier and Crehore, and on the other of Pollak and Viràg, demand careful attention. The experiments of the latter between Buda Pesth and Berlin appear to have come as a surprise to many Continental electricians not previously conversant with the Wheatstone automatic transmitter; while the suc-

cess that they have obtained in sending words at the rate of 1,300 to 1,500 words per minute over a land line 475 miles long once more raises the familiar question whether a mile or two of subterranean cable inserted in the line would not have effectually barred the transmission and reduced it to ordinary rates. We need not believe all the nonsense telegraphed by special correspondents to the daily press from Vienna, that home of scientific canards. But Pollak and Virág's results are of more substance than the imaginary achievements of Jan Szczepanik. It is interesting to note that in their experiments success was largely due to the use at each end of the line of an inductive shunt—a device advocated so strongly for cables by our late Past President, Mr. Willoughby Smith.

When we turn to the question whether such rapid methods of signalling will prove of any use on subterranean or submarine cables, we are still confronted by the old difficulty that no improvements whatever in apparatus at the ends of the cable will get rid of the sluggishness inherent in the cable itself, if constructed upon the traditional patterns. The suggestion which I advocated in 1893 of accelerating the speed of signalling by attacking the problem in the middle instead of tinkering at the ends has not yet borne fruit. My suggestion to construct cables with a series of self-inductive artificial leaks of high resistance distributed all along its length to combat its distributive capacity appears to be too radical to be acceptable to the cable authorities. But it is self-evident that whatever good an inductive shunt (or artificial "leak") at the end of a cable will do in getting rid of the static charges, an inductive shunt (or artificial inductive "leak") at the middle will do just twice as much. Why, then, should the suggestion to utilise this known property at one or more points along the length of the cable not be put to an experimental trial?

Of the tendencies in the telephonic world I forbear to speak. Great Britain has little reason to be proud of her record—past and present—in that line. She allowed the microphone, freely given to the world by its too generous inventor, to be exploited as a monopoly by others.

The competition of electricity with gas as a means of illumination has been rendered very severe by the improvements introduced during recent years in incandescent gas

lighting. The discovery of the properties of the rare earths in giving an augmented illumination—the result of a purely scientific research—was the foundation of the invention of the Welsbach mantle. It is singular that the very same properties were not turned to account in electric illumination before the invention by Nernst of the lamp which bears his name; a lamp for the commercial introduction of which electrical engineers are still waiting expectantly. Meantime a far more important factor in the economic struggle remains in a possible reduction of the high prime cost of electric wiring of buildings. Could electric house wiring be carried out as simply and as cheaply as the putting in of gas-pipes an enormous advance might be confidently expected. But so long as our station engineers and our fire-insurance inspectors insist on having both wires fully insulated, and do not allow an uninsulated or a semi-insulated return conductor, so long will this advance be delayed. With the introduction of armoured conduits for interior wiring, surely the prejudice which requires a double insulation will disappear.

In the public distribution of electric energy for lighting and power the necessities of economic working are effecting a slow but sure revolution. The methods that were in vogue at the date when the Electric Lighting Act of 1888 made electric distribution in this country commercially possible are being superseded. Larger generating units are being used in our stations. Larger areas of supply and fewer generating centres in an area are a necessity of the time. From the row of little bipolar dynamos, each with its own small high-speed engine—a sight so familiar in the older lighting-stations of this country—we are gradually passing to the use of large multipolar machines coupled to larger and more economical steam-engines. Ten years ago, a distribution at six miles from the generating station was looked upon askance by many electrical engineers. To-day it is recognised that the secret of economical work is to generate on the large scale—"in bulk" as the phrase goes—and to distribute over large areas at an appropriately high voltage. Whether the prime source of power be hydraulic or thermal, the problems of economic distribution are essentially identical. Two of the most recent examples—both of water-power stations—must

suffice. At the Kanderwerke at Spiez a pressure of 4,000 volts suffices for the distribution of current for lighting and power within a radius of six miles; but for the thirty-mile distribution from the same station to supply the city of Berne and the Burgdorf-Thun railway a 16,000 volt pressure is adopted. The city of Milan, which is lit by power from the hydraulic station at Paderno, twenty-four miles distant, receives its currents at 13,500 volts. When electric energy is thus generated and distributed on the larger scale the time-honoured methods suitable for parochial areas must give way to newer ones of greater economy. Continuous current generators and motors are unsuitable for operation in such wise at economic voltages. The great superiority of alternating currents asserts itself here uncontested. And with the greater economy of copper that is afforded—in the transmission at a given superior limit of voltage—by the use of three-phase currents, commercial considerations of the most elementary order decree that the fittest shall survive. It was, doubtless, in its time a great advance when the late Dr. Hopkinson in this country, and independently Mr. Edison in America, introduced the "three-wire" system, in which by the employment of a central or neutral wire three copper conductors were made to suffice where four conductors had previously been needed. The obvious economy of using *one* neutral wire instead of *two* separate return conductors was sufficient to secure its rapid adoption. But with the introduction of the three-phase distribution we may now have three wires doing the work of six, each wire, when the circuits are equally loaded, serving as a return for the currents of the other two. In cases where, as in three-phase lighting, the three lines are not equally loaded, we may, by adopting a Y-grouping with a neutral wire leading back to the common junction have *one* neutral wire serving in the place of *three* separate return conductors; thus carrying forward Dr. Hopkinson's idea to its logical extension. Experience in Heilbronn, in Strassburg, in Lyon, and a score of other places proves that the fear formerly expressed as to difficulties in balancing the circuits is unfounded. In the light of such experience it is not premature to say that the use of the three-wire system with continuous currents is obsolete. Obsolete it is not, however, in the sense of being *disused*. *Obsolete* it is, in the

sense that a better and more economical method is known and is already largely in use. Of all the new lighting stations now under construction in middle Europe, quite two-thirds are designed for three-phase work. Even in Berlin, where the admirably engineered group of lighting stations on the continuous-current plan has been eminently successful, financially and technically, all extensions are being made on the three-phase plan; and in a few years the whole will probably have been converted to alternating currents.

While the continuous current is, of course, the only species admissible for electrolytic work with all its rapidly growing applications in the chemical industries, the superiority of alternating currents for motive power and for all long-distance work is every day becoming apparent. Only a very short time ago it was the fashion to decry alternating currents on the alleged ground that alternating current motors were not self-starting. That reflection might have had some weight ten years ago. But the simple truth is that continuous currents will not work motors at all except toys of the old Barlow wheel type. Let him who doubts this statement ask himself what is the purpose of that costly organ, the commutator, which is an integral part of every so-called continuous-current motor. The sole function of a commutator is to commute a continuous current into an alternating one, or *vice-versâ*. If a continuous current will drive a motor, why go to the expense of putting into any motor a commutator to commute that current into an alternating one inside the machine? Moreover, the unnecessary commutator—for it is unnecessary if the currents are supplied to begin with as alternating currents—introduces the risks attendant upon the use of "brushes"—risks which have led the insurance companies to prescribe that all motors with commutators should be put in fire-proof enclosures. Let it be once realised that the commutator is an unnecessary excrescence due to the supply of a particular kind of current which won't work a motor until commuted, and that, with the supply of the proper kind of current, no commutator is needed, and before long we shall see these restrictions withdrawn. A common grindstone is a thousand times more likely than a well-constructed modern commutatorless motor to cause an out-

break of fire. Yet no one prescribes fire-proof enclosures around grindstones in any ordinary factory.

Another tendency of the times is the simplification of the switchboard, its construction of fire-proof materials throughout, and with more room both before and behind for the good arrangement of gear and connections, and the avoidance of an unnecessary multiplication of fuses. The avoidance of step-up transformers by direct generation at high voltage is in itself an obvious step toward simplification.

In the working of alternate-current generating stations, where parallel running of a number of generators is a necessity, the station engineer has always had before him the fear of a serious breakdown should anything happen to one of the generators. If the field magnet of any one generator loses its magnetism through any failure of the exciting current, then all the other generators instantly pour an immense current through its armature, with dire disaster not only to it but to the station as a whole. All manner of devices have been designed to combat this dread eventuality. Fuses and safety-devices of every description, including automatic disconnecting gear warranted only to operate for currents in opposition of phase, are found not always to do their duty. Much discussion has arisen as to whether the excitation of alternators in parallel ought to be an excitation in parallel, or whether each alternator ought to be provided with a separate exciter on its own shaft. Even excitation in duplicate from two independent sources has been tried. It is satisfactory to note that a means has been discovered which will entirely remove this source of anxiety, and render such accidents impossible in the future. Let me here narrate a test described in a recent number of the *Bulletin de la Société Internationale des Électriciens* (December, 1898, p. 498) upon two alternators of 250 kilowatts each, direct-driven at 67 revolutions per minute by two horizontal compound engines, the alternators being constructed by the well-known house of Farcot. Both alternators were separately excited, and were synchronised together and put in parallel in the usual manner. While thus running, the excitation was suddenly cut off from the field-magnets of one alternator, and *then the steam* was cut off from the *engine of the other alternator*, which remained excited.

Both machines continued to turn, the unexcited alternator continuing the supply, furnishing current for the lighting circuit and also supplying enough current to continue to drive at nearly normal speed the other machine and its engine. This extraordinary test, repeated many times, took place in the electric lighting station of St. Ouen. The explanation lies in the construction of the alternators. Their revolving field-magnets are furnished, on the plan suggested by Monsieur M. Leblanc, with the device termed by him an *amortisseur*, which is nothing else than a simple and substantial squirrel cage of copper embedded in the pole-pieces of the field-magnets, each pole being perforated with six slots to receive six stout copper rods, the whole of which are short-circuited together by two external rings of copper. We are all familiar with the device of the embedded squirrel-cage construction introduced by Dobrowolsky and Brown nearly ten years ago into the so-called *rotors* of polyphase motors. In these motors the squirrel-cage structure revolves at a slightly lower speed than that of the revolving magnetic field ; and it has long been known that if the same structure is mechanically caused to revolve at a speed slightly above synchronism, the machine becomes a generator, taking power to drive it. In brief, the induced eddy-currents in the copper structure, when revolved above or below synchronism, magnetise it and make it act as a field-magnet. Leblanc, adapting this device to the actual field-magnets of alternators, has not only simplified the operation of synchronising, but has given to the alternator the new and remarkable property that, on the failure of the excitation from the ordinary source, the automatic action of the eddy-currents comes into play, and thereby entirely prevents the disastrous reactions which have been so much dreaded by station engineers. I regard this invention as one of the most important of recent years. It has been applied also to the 600 kilowatt alternators in the sector of the Champs Elysées in Paris.

Passing from the generation of current to its utilisation for electric traction, the most notable evolution now in progress is that of the application of electric power to heavy railways. The application to street railroads — in other words to mere tramways—has been an accomplished fact for ten years on the other side of the Atlantic, where there

are now thousands of miles of electric tramways, mostly operated from overhead lines from which the current is taken by a contact trolley-wheel. If in this country the development of electric tramways has been slower, we have at least the advantage that our cities are not disfigured by networks of overhead trolley lines. No such objections hold good for rural districts, and slowly but surely both the industrial and agricultural districts of England are being furnished with electric intercommunication with its many attendant advantages. It may come as a surprise to many who think England behindhand in this respect, when they learn that while the total subscribed capital invested in this country in 1899 for public electric supply is about £17,800,000, no less than £20,800,000 is already invested in electric traction. Of the effect of the introduction of electric traction as a social and economic factor I have spoken elsewhere. There can be no question of the immense social benefit, particularly to the artisan population, afforded by this means. But the electrical engineer is now engaged on the still greater problem of operating heavy railways, and the development in this branch is being watched with keen interest. The two deep-level railways in London, the City and South London Railway and the Waterloo and City Railway, both of which have amply justified their promoters, are shortly to be supplemented by the Central Electric Railway, an undertaking of much greater magnitude, while several other similar schemes are either under construction or authorised. In the City and South London Railway the rolling stock is designed for separate electric locomotives each drawing three passenger cars. The gauge is 4ft. 8½ins. On the Waterloo and City line the trains consist each of four cars, of which the two end ones are fitted with motors, four motors on each terminal car, so that the train can be driven by either set of four motors. Each train can carry 204 passengers. The gauge is 4ft. 8½ins., but owing to the size of the tunnel ordinary railway rolling stock could not be used. In the Central London line the gauge is also 4ft. 8½ins. The locomotives, each with four gearless motors, weigh 35 tons each. Each will draw a train of seven cars, with a seating capacity of 336 persons per train. The total length, including sidings and cross-over lines, exceeds eight miles of double track.

In all three of these railways the current is taken from a third rail on the surface, and the return circuit is through the ordinary rails, which for this purpose are bonded with copper bonds. All these lines are operated by continuous currents at 400 to 500 volts. In the case of the Central London line, part of the feeding is effected through rotatory converters which receive three-phase currents from step-down transformers.

In sharp contrast to these three London undertakings is the Burgdorf-Thun railway in Switzerland, which was opened in July last. It is in every sense of the word a full-gauge railway. Not only is its rolling stock full gauge (the full gauge of Switzerland is 4 ft. 8½ in.), but the railway admits of use by ordinary steam locomotives, drawing ordinary trains. The electric rolling stock is of two kinds—automobile cars carrying 66 passengers each, for use singly or in pairs, and locomotives of 300 H.P. each, for drawing trains of ordinary carriages or goods wagons. This railway is worked by alternating currents supplied in three phases, at 750 volts, the feeding being effected through stationary transformers at 16,000 volts. The currents are taken from two overhead conducting wires, the rails serving as the third conductor. The length of line thus electrically equipped is 40 kilometres, or 26 miles. The arrangements were designed, and the electrical equipment constructed, by Messrs. Brown, Boveri & Co., of Baden, who were the first to apply three-phase currents to traction. In the Lugano tramways as a commencement, then in the steep mountain light railways of Engelberg, of the Gornergrat, and lastly of the Jungfrau, they gained experience in this method, which now stands triumphantly demonstrated in its adaptability to the service of heavy lines. In the United States heavy railways have been to a very limited extent operated by electric locomotives. Some built for the Baltimore and Ohio Railroad, weighing about 90 tons, are employed to draw ordinary trains over a short line around part of the city of Baltimore. They work with continuous-currents from overhead trolley lines.

There can be little doubt, however, that to Switzerland rather than to America we must look when desiring guidance as to the future development of this problem. All necessary data now exist for the exact working out of the necessary

equipment of any given line, actual or projected. No experiments are needed to enable the constructor to proceed, so soon as it shall have been determined which kind of current is to be used. Already it has been found in the designing of the Central London line that continuous current methods, however suitable for light and short railways, and for tramways where frequent stoppages occur, fail when the current has to be supplied from a distance of several miles, alternating currents being brought in because of their greater economy in transmission. The extraordinary thing is that this having been so far grasped, the whole of the rest of the equipment was not designed to match with three-phase motors, instead of introducing the complication of rotatory converters to work continuous-current motors. Time alone can show how the mixed system adopted will work in practice. To me the choice of the mixed system appears of doubtful wisdom. Perhaps the distinguished engineers who are understood to be spending £30,000 on experiments for the Metropolitan Railway to enable them to recommend the best system for our inner circle underground line will shortly be able to report whether a simple three-phase system throughout is, or is not, more economical than either a continuous current system throughout or than a mixed system with converters. If they do not settle this question, which is to-day the one important question in electric railway work not yet settled, we must regard the expenditure as pure waste.

Returning to the question of electric tramways, the problem of the hour is the equipment of busy city thoroughfares, where for obvious reasons overhead wires are inadmissible. To all the three possible methods that dispense with overhead construction, viz., by accumulators carried on the car, by use of slot conduits in the road, and by use of surface contacts, objections are not wanting. Accumulators are found too heavy and too short-lived to be satisfactory. Conduit constructions are objected to as too costly, and as interfering too much with the roadway, while to surface-contacts there is brought the terrible indictment—worse than any against the conduit—that nobody has had experience of them. You are aware that in this question of surface-contact systems of tramways I am an

tinct lines of progress, and some of these topics will doubtless form the subjects of discussion at our meetings during the session now beginning. I venture also to express the hope that the question of the distribution of electric energy on the large scale may be brought before our members for discussion. Nothing can be more helpful to the industry generally, just at present, than the free discussion of a topic which is likely again to engage the attention of parliament, and which ought to be discussed from the standpoint, not of restricted parochial or municipal interests, but of its bearing on the wider interests of national and public economics, and of the industry at large.

In commemoration of the centenary of the discovery of the pile, by Alessandro Volta in 1799, the city of Como, his birthplace, has this year held high festival. Beyond contest this discovery of a means of generating chemically a steady electric current constitutes the starting-point of the entire modern development of the science of electricity. Though that modern development turns upon the subsequent discoveries and inventions of others—the discovery of the magnetic properties of the current by Oersted, the invention of the soft-iron electro-magnet by Sturgeon, the discovery by Faraday of the fundamental principles underlying the dynamo and the transformer, together with many others of lesser moment—it still remains true that to the genius of Volta we owe the initial impulse. His memorable letter of June, 1800, to Sir Joseph Banks, first describing the pile, marks the opening of a new epoch in the history of civilisation. Without that discovery we now possess, neither telegraph nor telephone, neither electric light nor electric power, electrotyping and electroplating would exist. Commerce, diplomacy, warfare, and journalism would have remained in a totally different stage of development from that in which they are to-day. In brief, we should—with the modifying circumstances of the steam-engine existing for power and the gas-jet for light—be still living in the stage of civilisation of the eighteenth century.

The Volta centenary was commemorated at Como by the erection of an exhibition and the holding of a series of celebrations. Unfortunately the exhibition was destroyed on July 9th by a calamitous fire, in which not only a fine collection of modern electrical machinery was destroyed, but a

number of Volta's original manuscripts and a considerable part of his historical apparatus perished. Happily the original pile and numerous other relics were saved, and are now enshrined in the Civic Museum of Como. Nothing daunted, the citizens of Como reconstructed their exhibition, which was re-opened in forty-two days. Amongst the Como celebrations were held two Congresses: one a Congress of Telegraphists, in June; the other a Congress of Electricians, in September. No invitation to send delegates to the former was received by this Institution, and neither it nor the British Post Office was officially represented. Four English telegraphists, none of them members of this Institution, were reported as having been present. This Congress, having been convened by the Italian Minister of Posts and Telegraphs, and being attended by official delegates of various European Administrations, many of them telegraph engineers of the highest distinction in their various countries, it is extraordinary, to say the least, that the English Postmaster-General was not represented on the occasion. The Congress of Electricians was organised by the co-operation of the Physical Society of Italy, of which Professor Ròiti of Florence is President, and of the Italian Association of Electrical Engineers, which has branches in Milan, Turin, Genoa, Rome, Naples, and Palermo, and of which Professor the Hon. Giuseppe Colombo is President.

At this Congress, at which distinguished electricians from France, Germany, Holland, Switzerland, and Finland were present, this Institution was represented by Professor Ayrton, Past President, and by myself. The Italian physicists and electrical engineers attended in great force. The proceedings of the Congress were carried on with great vivacity; and many matters of the highest scientific and technical importance were discussed in its various sessions. After the sittings were concluded, two days were devoted to visits to the large generating stations at Paderno and at Vizzola; the former taking power from the river Adda (which flows out of the Lago di Como), and supplying electric current for transmission at high voltage to the city of Milan; the latter, not yet quite completed, taking water from the river Ticino, which drains the Lago Maggiore, and distributing its currents to the industrial towns of Gallarate, *Legnano, and Somma Lombardo,* within a radius of some

twenty-five miles. Alike from the point of view of electrical and hydraulic engineers these stations are of the highest interest, presenting as they do special features different from those of almost all other kindred enterprises. Our Italian brethren may well be proud of the engineers who have found the solutions for these special problems of construction, and carried those solutions to practical success.

This year is also marked by the establishment, with a Government grant, of the National Physical Laboratory for the standardising and certification of scientific instruments, and for physical research on well-defined lines. Though thus commenced on a modest scale, the circumstance marks an event of national importance.

I cannot forbear to direct your attention to another matter of public interest, and one which exercises an influence on all attempts at developing new enterprises. It is only too notorious that the whole question of financial development of new inventions is in this country in a most unsatisfactory state. The promotion of joint-stock companies under the Limited Liability Acts has become a public scandal. In the eighties a heavy blow was given to the real progress of electric lighting by the reckless promotion of bubble companies with inflated capital, causing the loss of millions of money upon foolish and worthless schemes. In the year 1882 no less a total than £23,000,000 of nominal capital was registered in electrical company schemes alone. In the nineties a similar reckless speculation has been witnessed over bicycles and automobiles. Happily electric traction has largely escaped this curse; and it will be an evil day for any of the newer developments of electrical engineering if a like craze should overtake them. There is something amiss in our economic machinery when such scandals can recur. Nothing is more familiar to those who have to deal with new inventions or to those who as consulting engineers have to advise and report upon them than the ever-recurring difficulty of getting them financed on a sound basis. Suppose that there is an invention of a thoroughly sound character, properly protected by patents, but requiring time and money to establish itself commercially. Suppose that there is required a capital of from £10,000 to £25,000 to put it upon a commercial basis. In *the present state* of public finance in this country the

[redacted]

inventor finds himself in this difficulty. He must either raise the necessary capital privately by personal effort amongst his own friends, or he must put it into the hands of a promoter who will want to bring it out with a capital of at least £100,000. In other words it is almost impossible to find a middle course between a purely private affair and an over-capitalised swindle. We have, unfortunately, in this country no organisation corresponding to the Industrial Banks of Germany, to the enlightened management of which the financing of sound schemes on a moderate scale can be entrusted. Much more might be said on this topic. It is one which affects not our industry alone; but it affects ours perhaps more than any other industry, because the glamour which is attached in the public mind to everything and anything electrical is made use of by the unscrupulous financier to the detriment of honest promotion.

I have already alluded to the sums of money which have been invested in this country in the supply of electricity for lighting and power, and in electric traction. According to Mr. Garcke's invaluable *Manual of Electrical Undertakings*, from which I derive my figures, the aggregate subscribed capital in shares and debentures at the present date stands as follows:—

	£
Telegraphs	[illegible]
Telephones	[illegible]
Electric Supply Companies ...	[illegible]
" " Municipalities	[illegible]
Electric Traction	[illegible]
Electric Manufacturing	[illegible]
Electrochemical and Miscellaneous Concerns	[illegible]
Total	[illegible]

This hundred millions of subscribed capital is much less, it is true, than that represented by the total capital invested in railways or in many other domains of British industry. But it is this electrical industry and the scientific and professional elements associated with it which our Institution represents to-day. Competing as we have to do not only in foreign and colonial markets, but even in our own home markets, with the *manufacturers* and engineers of other

countries, it behoves us to do all we can to make our Institution of use to our members of all grades, and particularly to our younger members. One great duty which we owe to them is to furnish them with the latest information as to the progress of electrical development, the development not only of industrial undertakings, of new machinery, of new materials, and of new inventions, but also of pure science, upon which all technical developments are in truth based. From the very first year of our existence—1872—we have always issued, in our Journal of Proceedings, abstracts and extracts of scientific and technical papers published at home or abroad. Two years ago we joined with our colleagues of the Physical Society in bringing out in the monthly numbers of *Science Abstracts* a far more complete digest of electrical progress than we were previously in a position to produce. To carry on this publication both we and the Physical Society have had to devote considerable sums, and indeed one of the reasons why we had a year ago to raise the fees paid by our students was avowedly to meet the financial burden which we had thus assumed for the purpose of disseminating knowledge. I venture to think that every penny thus spent has been a most wise outlay, and one of which we are already beginning to reap the fruits. Our members all over the country and in distant lands are thus kept informed month by month of the progress of the science; and they increasingly appreciate their connection with the Institution. I know of no means better calculated to keep our younger men abreast of the times than by putting into the hands of every one of them this admirable compilation.

But the needs of our Institution do not end with the effort to keep our members informed of the progress of science. We have other demands upon our funds of a very pressing character. The Benevolent Fund established a few years ago upon an independent basis has, though small, been available for helping necessitous members. In this connection every member of the Institution will rejoice to learn of a great and generous offer which has just been made to us. One of our honorary members, Mr. Henry Wilde, F.R.S., a name memorable as that of the pioneer in the sixties of the early forms of dynamo machine, both continuous and

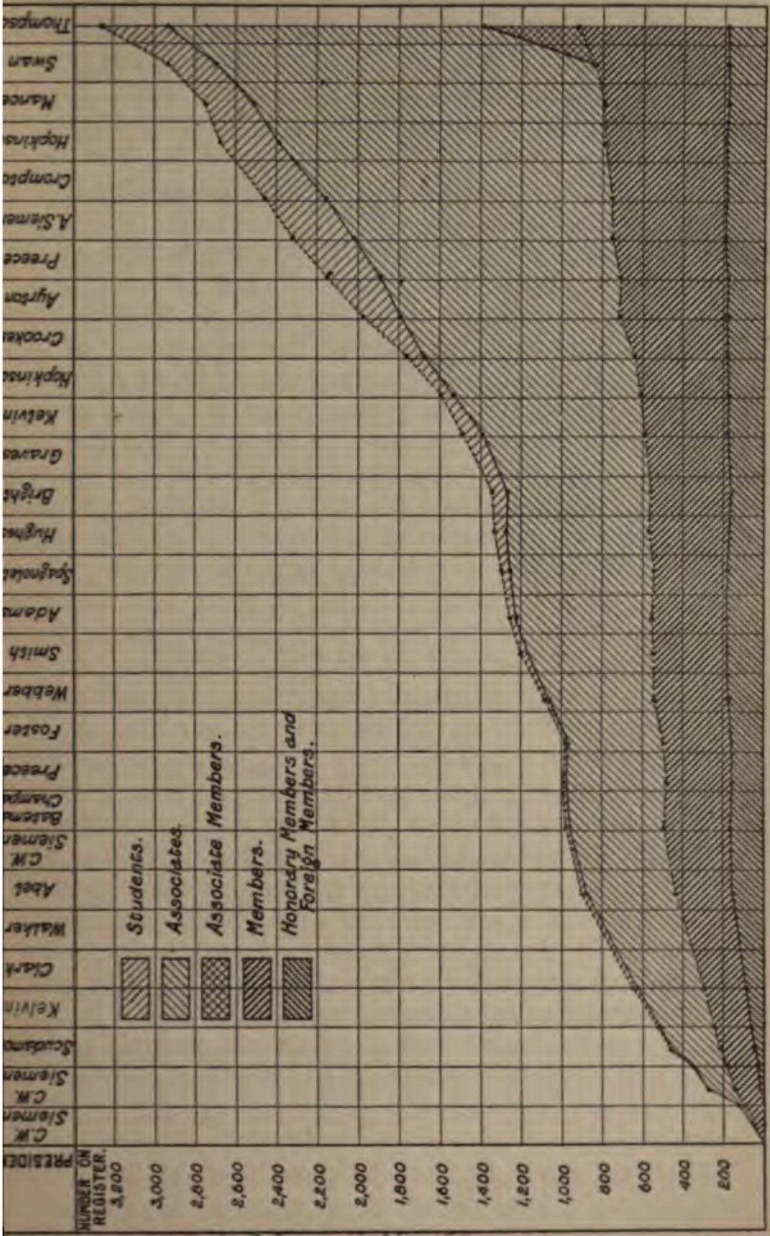
Swan
Mance
Preece
Ayrton
Kelvin
Graves
Bright
Hughes
Adams
Smith
Webber
Foster
Preece
C.W. Siemens
Abel
Walker
Clark
Kelvin
C.W. Siemens
C.W. Siemens
NUMBER ON REGISTER.
3,200
3,000
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
Students.
Associates.
Associate Members.
Members.
Honorary Members and Foreign Members.

FIG. 1.

alternating, and of their application to lighting, to deposition of copper, and to the transmission of power, has offered to the Institution, and the Council has accepted, a sum of £1,500 for the purpose of constituting a Benevolent Fund. I need only mention this to secure your cordial acknowledgment of the great generosity of Mr. Wilde, whom two years ago we elected an honorary member in recognition of his claims on the electrical community.

From the very beginning we have been accorded by our generous hosts, the Institution of Civil Engineers, the privilege and advantage of holding our meetings in this hall. If some of us feel that with the rapid growth of our own body the time is coming when we ought to be taking active steps toward providing ourselves with a home of our own, it is not because we are not deeply grateful for that privilege. Nay, rather the circumstance that our growth compels us to contemplate this step is a perpetual reminder of the courteous generosity which has itself been no small factor in promoting our welfare and our increase. The founding of our Building Fund six years ago was due largely to the foresight and fostering care of our then Treasurer and Vice-President, Sir David Salomons. At his instigation we have annually set aside such sums as we could spare from our surplus income, and our nucleus of a Building Fund stands this autumn at £5,000 so accumulated. The Council has for some months been quietly prosecuting inquiries for a suitable site; and it has recently decided to issue a circular drawing attention to the Building Fund, and suggesting to members of all grades the expediency of subscribing for the next few years an annual contribution thereto. If by this means we can treble or quadruple our present fund, we shall be ready at least to begin to build when a suitable site shall have been found. And it is most earnestly to be hoped that the generous example of Mr. Wilde will stimulate others of our wealthy members to rival his gift by valuable donations to the Building Fund.

Finally, I would speak of the growth of the Institution itself. From a total membership of 110 in 1872 we have increased, as the accompanying table shows, to a total of 3,254 at midsummer, 1899, and the statistics show clearly that the rate of increase is itself increasing. In the establish-

ment of the new class of Associate Member we think we have secured a new element of strength. With the growth of total membership has come a new movement for the grouping of our provincial members in local branches. The Council has appointed a committee to organise these; and already preparations are on foot for constituting two local centres in the north, and another in Ireland; while our South African members have already constituted themselves informally into a local branch, holding meetings in Cape Town, which will shortly be officially recognised under our new Articles of Association. All these are signs of active progress. The novel departure made last summer, when the Council sanctioned the suggestion of an official visit to Switzerland, has already borne fruit in many ways. The Swiss tour brought together many of those who, though active members of the profession, cannot often attend the ordinary meetings in London. It not only enabled us to see what Swiss engineers are doing; it brought us into the most pleasant personal touch with our able and courteous Swiss *confrères*, and it procured for us an invitation to pay a similar visit to Germany at a date in the near future. But, best of all, it has, I think, enabled some of us to realise more fully than we did before the value of our connection with our own Institution of Electrical Engineers; it has taught us what the power and usefulness of our Institution may be; and it has knit us together and inspired us to do what we can to promote its prosperity and the prosperity of the great industry which it represents. In this spirit, and with the note of progress sounding in our ears, let us carry on the work of the session now opened.

MR. R. KAYE GRAY: I have great pleasure in being the medium of conveying to Dr. Thompson our thanks for his extremely lucid paper. Every one in this room knows that when Dr. Thompson sets himself to work to describe to his fellow-members the things that he has in his mind he does it well, and I think that to-night we have certainly had an example of his power. It would be quite superfluous for me to say any more about a man so well known to us all, and with these few words I move "That the best thanks of this Institution be accorded to Dr. Thompson for his most interesting and valuable address, and that, with his

permission, the address be printed in the Journal of the Proceedings of the Institution."

Mr. MORDEY: The honourable task has been imposed upon me of seconding this resolution of thanks for this admirable address. I do so with very great pleasure—indeed with particular pleasure. We have known Dr. Thompson in a great many capacities—as teacher, as writer, as investigator, and as a historian of electrical progress. And now we see him in a new capacity—in two new capacities, as President of this Institution and as a prophet. For to-night he has departed from the usual practice. In his Presidential address he has dealt, not with the past, with which he is very competent to deal—as are all successful prophets—but with the future. This has been a fighting address. Dr. Thompson has peered into the future; he has seen things that are happening in that future, and he has come here and told us what those things are. I think that we might do a great deal worse than devote the rest of this session to discussing the Presidential address.

The vote was carried by acclamation.

The PRESIDENT: I need not say that I thank you very heartily for your appreciation of my attempt—not to predict the future, for certainly I do not admit that I am qualified to play the *rôle* of prophet—but I think I may be able to discern certain tendencies, a certain trend in the progress of events, and I thought it might be well to point out to you those which appeared to me to be significant.

While thanking very kindly Mr. Gray and Mr. Mordey for the words of appreciation which they have expressed, I should certainly not desire that the whole of the rest of this session should be devoted to the discussion of my address, because we have already adopted a programme for our session. A considerable number of papers have been offered, to which the meetings in the immediate future are already allocated.

The Three Hundred and Thirty-sixth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday evening, November 23rd, 1899—Professor SILVANUS P. THOMPSON, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on November 16th, 1899, were read and approved.

The names of new candidates for election into the Institution were announced and ordered to be suspended.

The following transfer was announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Archibald Allan Crawford.

Messrs. C. W. S. Crawley and E. W. Lancaster were appointed scrutineers of the ballot for new members.

The PRESIDENT: The Council has given its sanction to the holding of an exhibition of photographs in the library of the Institution, from the 5th to the 12th of September, the week during which our dinner is held. The photographs for exhibition are those taken by members during the Swiss tour, and will afford reminiscences of that very agreeable time when we were together in Switzerland.

I have also to announce that the Council has decided to hold a meeting of members of the Institution in Paris on August 16th, 1900. You are all probably aware that at the Paris Exhibition certain conferences or congresses will be held. Among these there is a Congress of Electricians, which, it has been arranged, will be in session from the 18th to the 25th of August. No doubt a number of members of this Institution will be desirous of paying their visit to Paris at that time, in order that they may be present at one or more sittings of the Congress. We have arranged our meeting for the 16th, just two days before, so that we may be able to hold a discussion before the Congress itself meets. We hardly know yet what formal business will be brought before the Congress, but we hear that there are

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certain propositions coming up about the electrical units, and it is well that we should have an opportunity, if anything is to be discussed internationally at the Paris Congress, of holding our meeting a little before, and arriving at our own conclusions. It is also possible that one sitting of our meeting may be held in common with members of the American Institute of Electrical Engineers, a number of whom, it is known, will be in Paris at that time. Indeed, the President of the American Institute of Electrical Engineers, Mr. Kennelly, has written to us informally, asking whether such a joint meeting of English and American electricians would be possible; and our Council has replied that we shall be most happy if such a joint meeting can be arranged as part of our meeting there.

The following papers were then read :—

THE COST OF STEAM RAISING.

By JOHN HOLLIDAY.

In the earlier days of the steam-engine it was customary to measure the efficiency of steam plant by the amount of work done by a given weight of coal, and this was expressed by giving the weight of coal consumed per horse-power per hour, allowance sometimes being made for the quality of the coal used. At that time, when a single boiler or range of boilers supplied steam to but one, or at most a pair of engines, and the boiler was laid down at the same time as, and as an integral portion of, a new steam-engine plant, and was, more often than not, supplied by the maker of the engine as part of his contract, this method of estimating was not so wholly misleading as it is in the present day, when a single boiler or range of boilers often not only supplies a large main engine, but many auxiliary or independent ones, and also serves many other purposes. The practice has therefore arisen of expressing the efficiency of an engine by stating the quantity of steam it uses per horse-power per hour, thus eliminating entirely all questions of the quality of the fuel, the efficiency of the boiler for transmitting the heat of that fuel to the water, and of the furnace and stoker, whether human or mechanical, in evolving from

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the fuel all the heat it contains. In this way the performance of a good engine is not marred by an indifferent duty obtained from the boiler, from any cause whatsoever. We have therefore on record the results of many engine trials, given in figures which take no account of the performances of the boiler by which the steam they used was supplied, and we have also many recorded tests of steam boilers determined quite apart from any question of power involving the employment of a steam-engine. Again, we have many instances given of the cost of steam power, the best of which are summed up by Professor Unwin in Chapter III of his work on the Development and Transmission of Power;[1] but in all these cases, in order to arrive at the cost of the steam power, it has been, of course, necessary to include the working and cost of both engine and boiler; and whilst a steam-engine cannot perform any useful work when dissociated from the steam boiler, the boiler can, and often does, perform many useful functions other than in the production of power by means of a steam-engine, and it is to the cost of producing steam, quite apart from the question of power, that attention is directed in this paper. A ton of coal may cost, say, 8s. when delivered on the stoke-hole floor, and we may, in a general way, consider steam delivered from the boiler into the steam main as the manufactured article of which the coal is the chief but not the only raw material used in the process of manufacture; the question then becomes what is the increased value of this ton of coal when delivered in the form of steam into the steam main? The other items which, with the cost of fuel, go to make up the total cost of steam produced are working expenses, maintenance of boiler and plant, capital charges, rent, rates, taxes, etc. In almost all cases, the cost of the fuel is by far the greatest part of the whole cost, and it can only be in the centre of the coal-fields, or some other equally favoured spot, where it is probable that the cost of the fuel will be anything less than 50 per cent. of the total cost, exception being of course made of those cases in which waste materials, by-products, or refuse, which might otherwise have to be removed at some expense, are used as fuels for steam raising. This being the case, the cost of fuel re-

[1] "On the Development and Transmission of Power from Central Stations," by William Cawthorne Unwin, F.R.S. (Longmans, Green & Co.).

quired to convert a given quantity of water at a given temperature into steam at a certain pressure gives a fairly relative idea of the cost of raising steam in districts where similar conditions and prices of fuels obtain. Mr. Bryan Donkin, M.Inst.C.E., has largely used, as a basis of comparison, the cost of fuel required to evaporate 1,000 gallons, the water being at a temperature of 60° F., and the steam evaporated at 60 lbs. per square inch above atmospheric pressure, or else the temperature of the water is taken at 212° F. and evaporation at atmospheric pressure, or, in other words, evaporation is from and at 212° F.; in any case a reduction to a common basis is easy when the conditions are known.

The following formula gives a ready means of obtaining the cost of fuel to evaporate 1,000 gallons of water when its price and the quantity of water evaporated by one pound of it are known.

Let C = cost of evaporating 1,000 gallons in shillings.
„ P = price of fuel per ton in shillings.
„ W = lbs. of water evaporated per lb. of fuel.

$$\text{Then } C = \frac{P}{W} \times \frac{10{,}000}{2{,}240}$$

$$= \frac{P}{W} \times 4 \cdot 464$$

This is a useful figure, especially for comparison of boilers working in the same district, where the prices of various descriptions of coals may be taken to vary with the amount of heat that they will evolve, because it takes into account the efficiency of the boiler and furnace and also that of the stoker, whether human or mechanical; but, at the same time, the limits within which comparisons may be made on this basis are narrow, as it always shows a very great advantage in favour of the use of poor quality and low-price fuels, which might be almost or entirely counterbalanced by the consequent increased cost of other items which go to make up the entire cost of steam-raising. There will, however, be less likelihood of giving rise to misapprehensions if it be always borne in mind that this figure gives, not the cost of evaporating 1,000 gallons, but only the cost of the fuel *required to evaporate* 1,000 gallons of water.

Mr. Bryan Donkin has published figures from some tests he carried out with different kinds of fuel in the same boiler, the conditions in all cases being the same; the results are comparable on the basis of the cost of fuel required to evaporate 1,000 gallons.

Kind of Fuel.		Cost of Fuel per ton.	Water evaporated per lb. of Fuel.	Cost of Fuel per 1,000 gallons evaporated.
		s. d.	lbs.	s. d.
A	Dust Coke... ...	5 0	6 0	3 8
B	Dust Welsh Coal...	10 0	8 0	5 3
C	Large Welsh Coal	22 0	9 0	10 11

These figures go far to show the economy to be obtained by using inferior fuels, which, as a rule, are far cheaper on the basis of calorific power than higher-class fuels. No better example of this could be given than the comparison of experiments B and C in the table given above, where we see that a difference of 120 per cent. in the price of the fuel gives an increased efficiency of but 12·5 per cent. at an increase in cost of 108 per cent. Should it be possible in practice to transfer the total, or any fixed and definite portion of the total, heat of a fuel to the water contained in the boiler in the furnace of which the fuel is burned, the true value of that fuel for the purpose of steam-raising would depend directly on its calorific power, and it would be possible, the price of the fuel and its calorific value being known, to foretell the amount of useful heat that would be secured by the combustion of one pennyworth of the fuel in question.

A table showing the number of thermal units in one pennyworth of fuel of various qualities and prices was given by Mr. R. E. B. Crompton, Past-President, in his paper on the cost of Electrical Energy[1] read before this Institution in April, 1894, which is, by permission, reproduced in Table I. Some figures from this table will be found set out in Diagram I. These, like the preceding table, show the enormous advantage promised by the use of low quality and low-priced fuels, but, as there never was a gain without

[1] This Journal, 1894, vol. *xxiii.*, *p.* 404A.

some loss, we may briefly inquire what the possible losses and disadvantages of cheap fuels are—and they are many.

In the first place, in order to get the same amount of heat with a low quality fuel as with a higher quality under similar conditions, more fuel must be burned in the same time; then, if the boilers and furnaces are already working up to their full power with high-class fuel, either more boilers and furnaces must be put down, or the present furnaces must be enlarged, entailing an expenditure of capital (the interest on which must be set against the extra economy obtained) and occupying more room at an additional cost for rent; or else the fires must be worked harder, perhaps by the use of forced-draught probably causing the furnace gases to leave at a higher temperature, and thus carry to waste a larger proportion of the heat in the fuel than formerly. The mere fact of more fuel having to be fired into the furnaces every hour will entail more work on the stoker, for which extra wages will have to be paid either to the same or to additional men. The extra amount of fuel used will cause the fire doors to be opened, in the case of hand-fired furnaces, more frequently or for longer periods both for firing and for cleaning fires, whilst the extra amount of refuse taken from the furnaces will carry to waste a correspondingly larger amount of heat, and, what is of more importance, will often cost a great deal more in removal, particularly in busy manufacturing centres. Extra storage and space for fuel may have to be provided, and the wear and tear of the furnaces increased according to the extra amount of fuel used, rather than according to the amount of steam produced. Low quality fuels too, as a rule, require a stronger draught to burn them to the best advantage than better qualities; this may necessitate an expenditure for more chimney power in the case of natural draught, and larger fans and engines, of course using more steam to drive them in the case of forced draughts. In substituting inferior for better-class fuels we may expect a reduction in the cost of the fuel, depending on the differences in the ratio of calorific value to price of the two fuels, and an increase in working expenses, etc., depending on the increased amount of fuel used.

It may not be out of place to give here a word of warning to those who are invited by the manufacturers of special

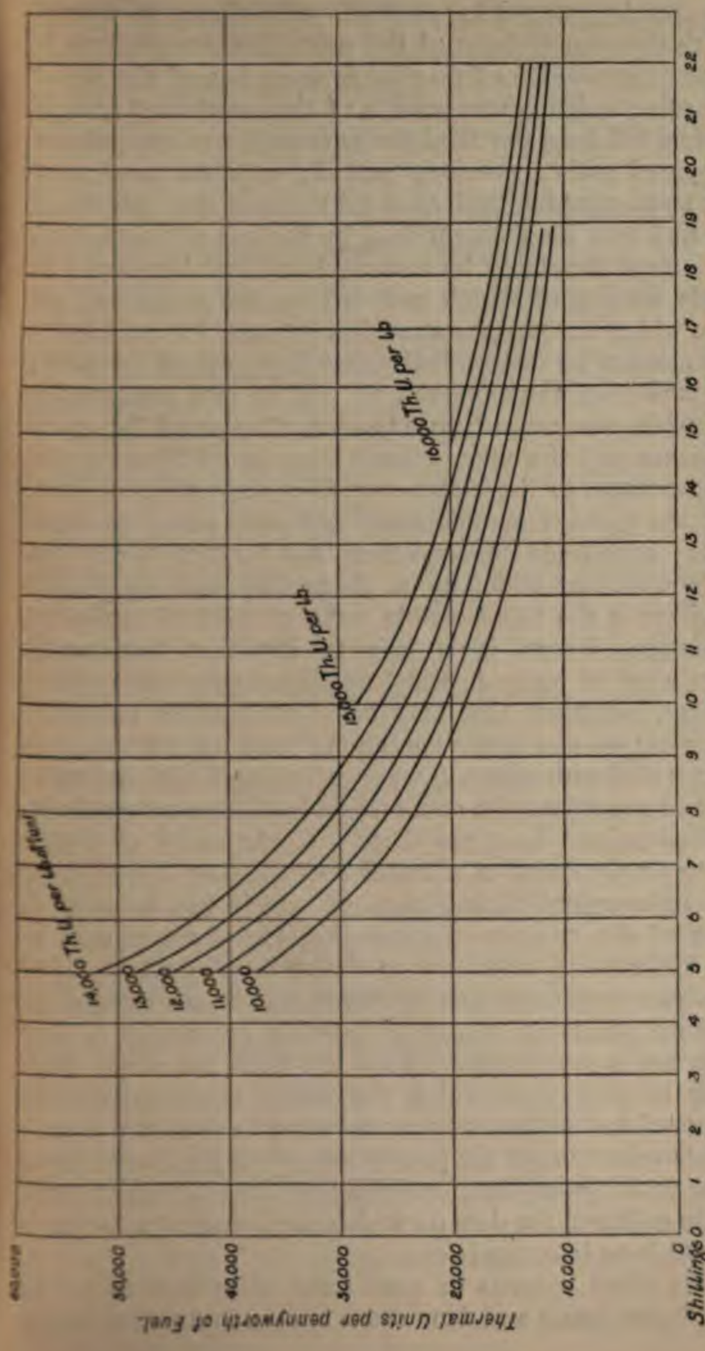

FIG. 1.—CURVES SHOWING THE NUMBER OF THERMAL UNITS IN ONE PENNYWORTH OF FUEL OF DIFFERENT QUALITIES AND PRICES.
From Mr. R. E. B. Crompton's Paper.

furnaces to enter into contracts with them, in virtue of which the manufacturer of the patent furnace shall take, as his remuneration for fixing the furnace, free of charge or at cost price, a definite proportion of the ascertained saving in the fuel bill from the time the new appliance was put in, as compared with a previous period; such an arrangement may seem very fair and reasonable, but if the reduction of the fuel bills be accomplished by the use of inferior fuel, there must inevitably be increased incidental expenses the whole burden of which will fall on the steam-user, and from which the furnace manufacturer will be entirely free. Still more to be deprecated is any arrangement based on a comparison of the amount and cost of fuel consumed on two trials, one made before the introduction of the special appliance and the other after it; for, in addition to other disadvantages to the steam-user, it is reasonable to assume that the furnace manufacturer will take pains to secure those conditions under which his furnace works best, whilst a furnace about to be discarded is scarcely likely to be either in the best possible order or worked to the best advantage; indeed it is safe to say that the vaunted superiority of many a special appliance over the ordinary furnace, whatever that may be, is attributable mainly, if not solely, to the better conditions obtained for it and the greater skill with which it was worked, and, with a reversal of these conditions, the result might have been reversed also.

It sometimes happens that a single range of boilers has to supply steam to a number of more or less different and independent plants, each of which has to bear its share of the expense of producing the steam it uses, so that it becomes necessary to determine the total cost of the steam produced and to divide that sum amongst the different plants as nearly as possible according to their respective consumptions. This has been the case with a range of boilers in which the author has been directly interested for the last six years; failing to find any records of determinations of the proportion which the fuel bill bore to the total cost of the steam delivered into the steam main, he has collected the data on which the following statements of costs have been made out.

The plant consists of nine Lancashire boilers in the *main boiler-house* and four spare boilers in another house,

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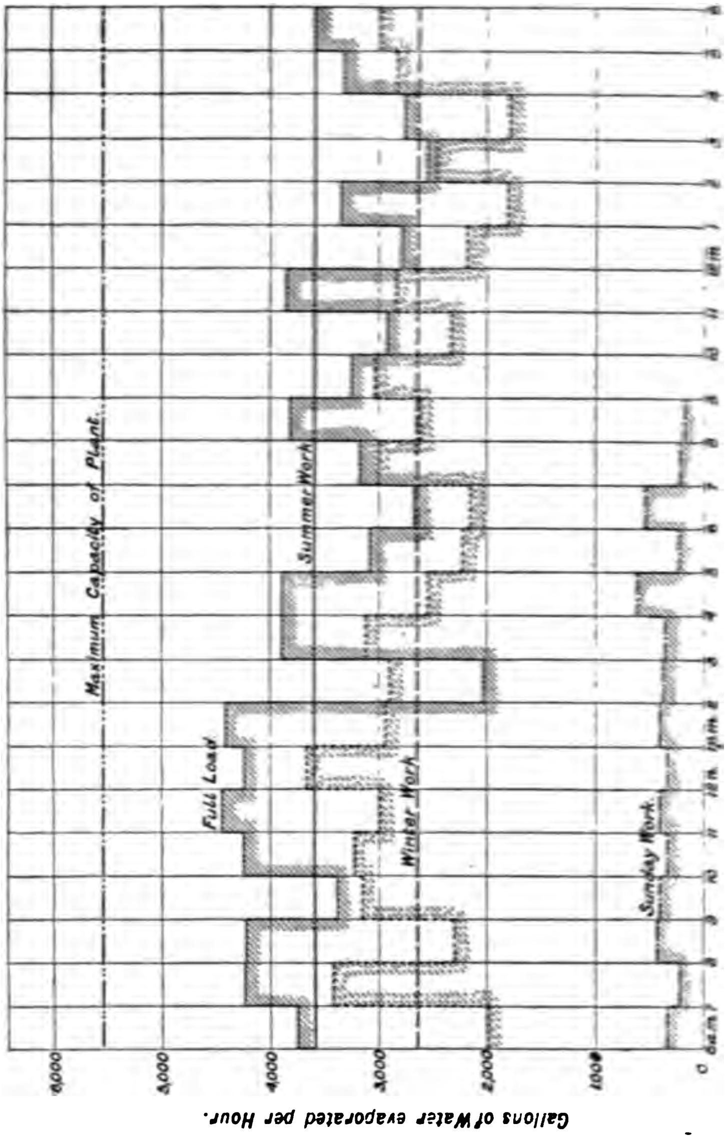

FIG. 2.—LOAD CURVES.

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connected to the same system of steam mains, but the latter used only as spare to the nine boilers in the larger house. The nine Lancashire boilers are of various makes and ages, none of them being modern, and vary in size from 6 feet 6 inches to 7 feet in diameter, and from 28 to 30 feet in length. They are arranged in two groups, Nos. 1, 2, and 3 being fitted with Perret's water-cased grates for burning inferior fuels, and deliver their products of combustion into a separate main flue and chimney from the other six. The latter are fitted with ordinary bars and are hand fired, Martin's balanced doors being used in the twelve furnaces of these six boilers. All the boilers are loaded to 60 lbs. pressure per square inch, and feed-water is delivered to the Lancashire boilers from a common feed main through three steam heaters, which are supplied with exhaust steam of up to 12 lbs. per square inch above the atmospheric pressure, and heat the feed-water to an average of 220° F. after it passes the feed pump on its way to the boilers. The demand for steam is fairly constant during the twenty-four hours (see Diagram No. II.), so that it is not necessary to bank up any of the fires or let down any of the boilers during any portion of the day or week except between 6 o'clock a.m. and 9 o'clock p.m. on Sundays, when two boilers only are kept under very easy steam.

In working these boilers, it has all along been recognised that steam was produced much more cheaply by the forced draught than by the natural draught furnaces, consequently the former were always worked up to their full power, and, as the minimum demand for steam almost always exceeded, except on Sundays, the amount the forced draught furnaces, by themselves, were capable of producing, they were seldom even damped down, and therefore worked under conditions extraordinarily favourable to economy; whilst the natural draught furnaces, having to make up the difference between the demand for steam and that produced by the forced draught furnaces, being fitted for that purpose with an automatic damper, were constantly varying between partial and full load, so that losses by unconsumed gases and radiation were abnormally great. This fact must be kept in mind, and allowed for, in comparing the results obtained in the two systems, and it will be seen from Fig. 3 that the six boilers fitted with natural draught furnaces gave much better results when doing the largest amount of work.

During seven months of the year seven boilers working together are able to supply the demand for steam, but during the later summer and autumn months the requirement is much greater and nine boilers have to be worked heavily, and sometimes even some of the spare boilers, which fact justifies the existence of the four reserve boilers which might otherwise constitute an extravagantly large spare plant.

The fuel generally used for the boilers with Perret furnaces is breeze, which is delivered in front of the boilers at the price of 3s. 6d. per ton. This fuel contains a large proportion of incombustible material (from 22 to 25 per cent.); the amount burnt is about 15 tons in 24 hours, or 1,400 lbs. per hour, or 18 lbs. per hour per square foot of grate surface, the total area of the six furnaces being 78 square feet; they evaporate from 5·5 to 6 lbs. of water per lb. of fuel; taking this at 5·8, the cost of fuel to evaporate 1,000 gallons is, by the formula given above—

$$C = \frac{P}{W} \times 4{\cdot}464$$

$$= \frac{3{\cdot}5}{5{\cdot}8} \times 4{\cdot}464$$

$$= 2{\cdot}69 \text{ shillings} = 2\text{s. } 8\tfrac{1}{4}\text{d.}$$

The quantity of water evaporated is about 2,700 lbs. per hour per boiler, equivalent to 135 h.p. at 20 lbs. of steam per horse-power per hour, a low result which eventually makes itself felt as one of the drawbacks to the use of inferior fuels. There being a plentiful supply of this breeze, it has been generally used during the period of these observations for these three boilers, some large coke being occasionally used with it; other fuels were tried at various times in other years, but none were found able to compete with it. The air pressure used for the Perret furnaces averaged about 1·1 inch of water column as measured under the fire bars, and was produced by a 36-inch fan driven by a belt from a special engine, the steam for which was taken from the boiler, and its amount is included in the figures given above, but due allowance is made in the proper place, both for the cost of the steam used and the interest on the capital sunk in the fan engine and other special appliances.

For the other six boilers various fuels have been used at

different times at prices varying with the state of the fuel market; in 1895, however, most of the work was done with a South Wales coal, consisting of about 30 per cent. large, the rest fine, which was delivered at the boiler at 14s. 6d. per ton; this fuel contained about 10 per cent. of incombustible, and under the existing conditions evaporated about 9·5 lbs. of water per lb. of fuel. Taking the cost of evaporating 1,000 gallons of water with this fuel, as was done above for the breeze, we have

$$C = \frac{P}{W} \times 4{\cdot}464$$

$$= \frac{14{\cdot}5}{9{\cdot}5} \times 4{\cdot}464$$

$$= 6{\cdot}81 = 6\text{s. } 9\tfrac{3}{4}\text{d.},$$

which is in remarkable contrast to the 2s. 8¼d. found to be the cost of the breeze to do the same work. In these boilers evaporation is at the rate of about 3,800 lbs. of water per hour per boiler, equivalent to 190 h.p. at 20 lbs. of steam per horse-power per hour, or 40 per cent. more power per boiler than in the case of the boilers fired with breeze.

We have, therefore, two ranges of boilers, one using a cheap fuel and producing steam at a cost for fuel of 2s. 8¼d. per 1,000 gallons evaporated at a rate equivalent to 135 horse-power per boiler, and the other producing steam at a cost for fuel of 6s. 9¾d. per 1,000 gallons evaporated at a rate equivalent to 190 horse-power per boiler.

We have now to consider the other items already mentioned, which go to make up the full cost of steam raising. The most important of these is working expenses, and in this labour is the heaviest. Under normal conditions seven boilers are under steam, viz.: Nos. 1, 2, and 3 fired with breeze, and four of the other six fired with Welsh coal. As the boilers are worked continuously the firemen are divided into three shifts, of which the two day shifts work three spells of three hours each between 6 o'clock a.m. and 10 p.m., and the night shift one spell of eight hours; thus for two hours in the day both sets of the day men are in the house together, and in this time some of the necessary cleaning, etc., is done. There are generally three men per shift, the two leading men taking three and four boilers each,

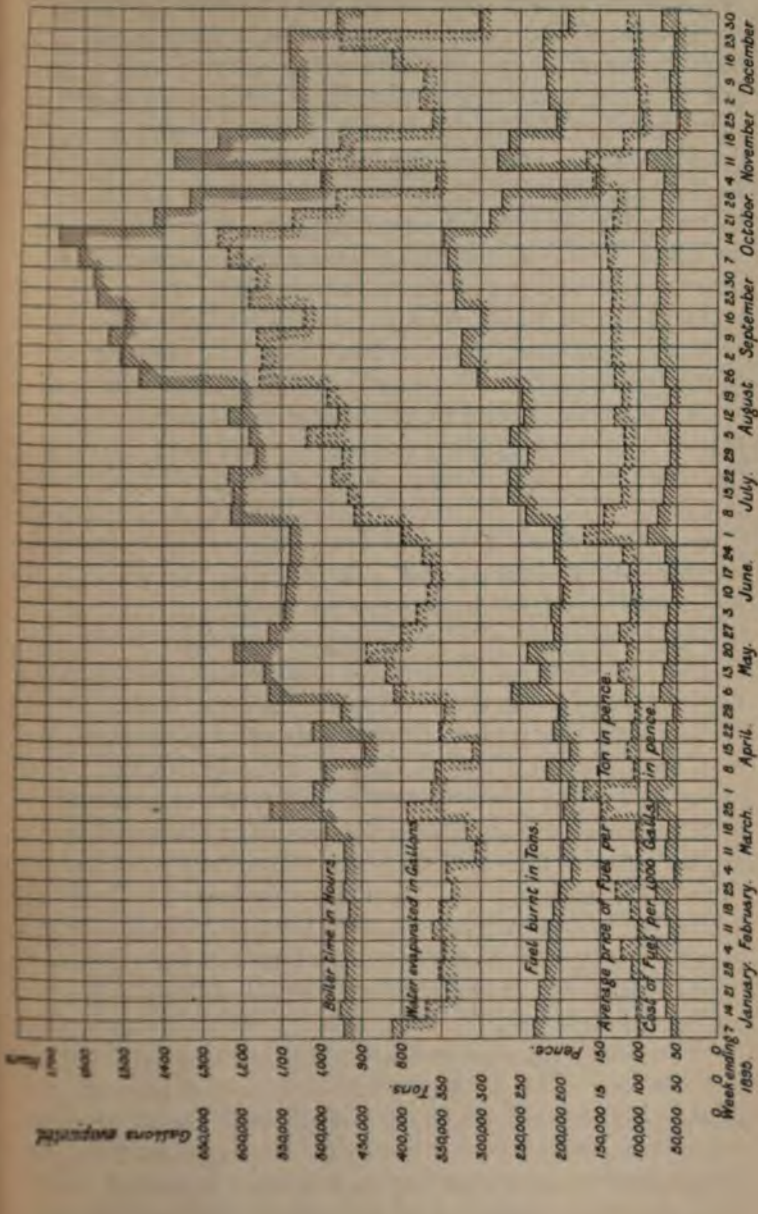

FIG. 3.—RESULTS WEEK BY WEEK.

and the third man assisting each of them as required. Taking the amount burned in 24 hours as 15 tons of breeze and 18 tons of the Welsh coal, the total amount fired per day is 33 tons by the nine men, or an average of 3·67 tons per man per day, not an excessive quantity when compared with the new Board of Trade rule for ships which allows one stoker for every 4½ tons burned per day; but the low quality of the fuel used on the Perret furnaces adds greatly to the labour of firing them, each of the six having to be cleaned out once in three hours or oftener. The firemen are paid at an average rate of 23s. per week, those working at night getting a shilling extra whilst doing so; they are under the charge of a foreman, who, however, has other duties to perform, so that a portion only of his time is charged against the boilers. A charge at the rate of £150 per annum is also made for the time which the engineer in charge devotes to this portion of his work. A boy is also employed for a portion of the day in the boiler-house in sweeping the tops of the boilers, etc. The expense of weighing the coal, and any incidentals connected with its receipt over and above the price paid for it per ton delivered, are included in the working expenses; these being the same per ton for all qualities of fuels constitute a heavier expense per 1,000 gallons of water evaporated by the inferior as compared with the better-class fuels.

During fifteen hours, between 6 o'clock a.m. and 9 o'clock p.m. on Sundays, which constitute the only light portion of the week's work, two boilers are kept under easy steam, the fires in the other being cleaned quite out in the morning and started again at night. The firing during Sunday is done by three men working, two of them five hours and one six hours, for which they are allowed time and a-half; whilst a second fireman works two or three hours in the evening as required in order to re-start the boilers that have been at rest during the day.

Flue-sweeping and boiler-cleaning is the item next in importance. The boilers using the inferior fuel are very thoroughly cleaned out at the end of each eleven or twelve weeks' run, during which time they have generally steamed from 1,600 to 1,700 hours each, and have deposited in their flues a very large amount of dust which, but for the forced draught, would require to be removed much more frequently; as it is, there is certainly a falling off in the amount of water

evaporated both per boiler per hour and per lb. of fuel burned, but not to such an extent as would justify the shutting down and cleaning of these three boilers five times a year instead of four as at present. This cleaning is performed not by the firemen, but by some of the general labourers attached to the concern; two men are able thoroughly to sweep and clean one boiler in four days, and in addition to their regular wages they are paid a gratuity of twelve shillings per boiler. In addition to the actual cleaning and removal of dust some expense is incurred in taking out fire bars, disconnecting air pipes, cleaning bars, etc., all of which are carefully overhauled at each periodic cleaning.

The natural draught boilers, fired with better-class coal, run for about the same length of time between cleanings as the forced draught ones, but as there are generally two of these idle, each boiler is cleaned only from three to four times a year; two men can finish one of these boilers in two days, and in addition to their wages of 5½d. per hour they earn between them the gratuity of twelve shillings for the job. Each cleaner is provided with a suit of overalls, which seldom serves for more than four boilers at the most. The expenses of cleaning out one of the natural draught boilers is far less than that of one of the forced draught boilers fired with inferior fuel.

The removal of refuse, viz., clinkers and ashes taken from the furnaces in the ordinary way of firing, and the dust removed from the flues during sooting out, amounts to a considerable sum during the year; the bulk of it is removed from the premises by a contractor at a fixed rate per load, but since an intermediate handling is necessary, the removal of an average week's refuse from the forced draught boilers during work costs about £2, and the amount removed from the flues at each cleaning about 11s. 6d. per boiler; whilst that from the natural draught boilers is removed for 16s. 6d. per week whilst in full work, and 4s. 6d. per boiler cleaned.

The feed heaters using exhaust steam are common to both groups of boilers, and the cost of cleaning them is taken according to the quantity of water evaporated in each group. The water used is taken from the town main, through meters, the cost being fourpence per thousand gallons; and as it is very pure, there is no expense incurred in treating it except for the addition of a small quantity of soda-ash which is necessary to prevent corrosion.

The cost of illumination is divided amongst the boilers according to the number of boiler hours worked; gas and electric light are both used—the annual cost is about £50. In the same way also the cost of the steam used to drive the boiler feed pumps is divided according to the quantity pumped, but in the case of the forced draught boiler a further charge has to be made for the steam used by the fan engine in producing the forced draught. The quantity of fuel to be charged against feeding the boilers is, however, very small, as a very large portion of the heat in the exhaust steam is recovered by passing the exhaust into the low pressure or exhaust main by which the feed-water is heated. Some experiments have shown that by utilising the exhaust steam from the feed pumps to heat the feed-water an economy of 1¼ per cent. in fuel can be realised. There are two quadruple acting steam feed pumps, each capable of delivering one gallon per revolution, which also act as water-meters; for this purpose they are fitted with counters which are read daily, whilst the pumps are calibrated periodically against a tank of known capacity to ensure correctness in the results; it is generally found that they deliver about 5 per cent. less than their full charge. A certain quantity of stores is of course used, such as shovels, firing-tools, barrows, soap, oil, waste, which in the course of a year amount to an appreciable sum.

The maintenance charges are somewhat more difficult to set out precisely for any given period than are the working expenses, as these vary from time to time, and a year is quite too short a period to ensure every item being fairly treated; some parts will come out too high or too low as repairs of any considerable extent happen to fall within or without the period under consideration. The figures given are those ascertained for the year 1895, and include somewhat heavy repairs to the pumps, and heavy items for renewals of non-conducting coverings of tops of boilers and steam mains; but in order to avoid errors the costs have been compared with those of previous years, and though the details differ, the totals agree very closely. The figures for maintenance are considerably less than they were expected to be when the investigation was taken up, but as the work was mostly done by the Company's own workmen, only charges for

labour and material are included; had the work been done by an outside firm, the figures must have been much higher and the average cost of maintenance would probably have

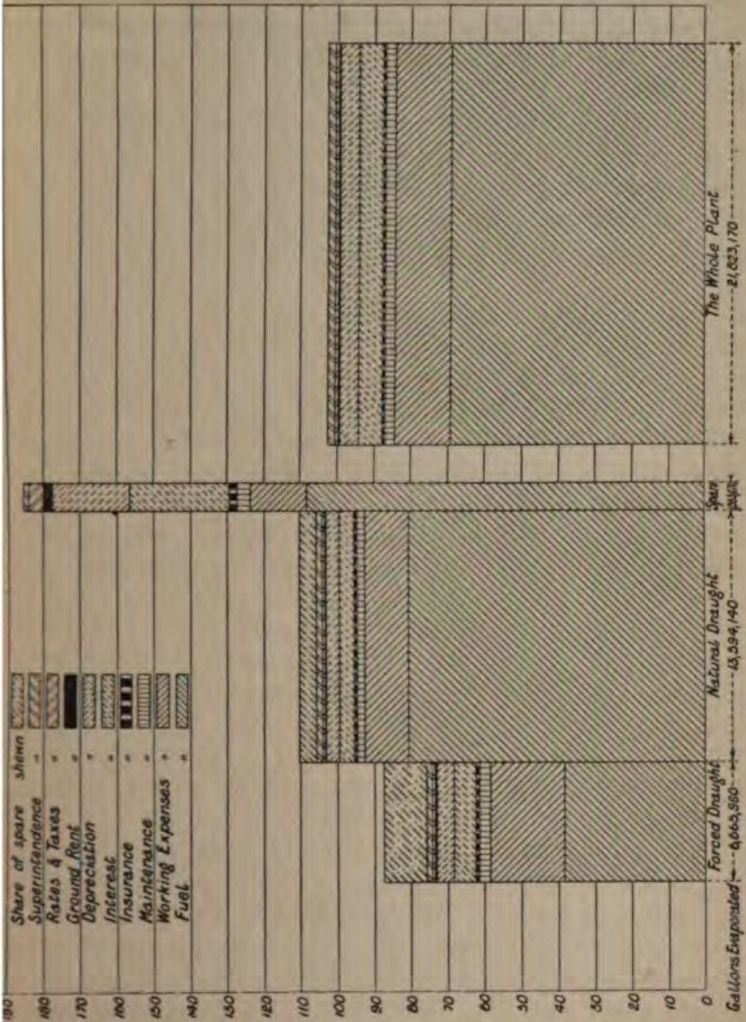

FIG. 4.—COSTS PER 1,000 GALLONS EVAPORATED.

been 5 per cent. of the total, instead of less than 3 per cent. as they stand in Table IV.

The fixed charges include the insurance of the boilers against explosions at *£2 12s. 6d. per* boiler per annum, and

it is worthy of remark what a very small proportion the cost of this excellent safeguard bears to the total cost of the steam made.

In calculating the interest on the first cost of the plant and buildings, it was found impossible to ascertain the actual original figures, so a careful estimate was prepared on the basis of present prices, on which the interest has been taken at 5 per cent. per annum.

Depreciation of boilers and machinery has been taken at 5 per cent. per annum, and of buildings, including chimneys, at 2½ per cent.; ground rent, rates and taxes having been approximated to local conditions as far as possible, and superintendences in proportion to the amount of the steam made.

The question of spare plant is one of extreme difficulty, and practice varies with almost every different case. In some instances, where an occasional stoppage is permissible, the amount of spare required may be nil; again, in cases where the boilers are worked by day only a small spare is allowable, because the interval between two days' work admits of minor repairs being carried out or temporary expedients resorted to. Where sufficient spare must be always available and the demand for steam small, then the spare plant must be fully equal to that in ordinary use; in other cases where the amount of steam made requires the use of several boilers, there is a point at which it is no longer necessary to maintain a full spare plant. In the case under notice it has been found that a spare plant of one boiler to every three in work is sufficient for all emergencies. This, of course, is based on the maximum and not on the average output of steam, consequently the spare plant has been comparatively very little used, but, as it exists, it has had to be kept in order, and it is a recognised fact that a boiler idle may deteriorate as fast as one in work; it has been kept in complete working order, and worked occasionally. Of course the cost of steam produced by these independent boilers is much greater in almost every way, than that made in the main boiler-house, as the statement in Table V. will show. The extra expenses of making this steam over and above those of that made in each of the two groups in the main boiler-house have, in order to determine the full cost of the steam *made in each,* to be added to the ascertained expenses of

those groups. It is, in the first place, difficult to decide what share of the expenses of the spare plant should be debited to each group of boilers in the main house, but, since the forced draught boilers were always worked when possible to their full fuel capacity, and had no self-contained spare as had the natural draught boilers, it has been considered right, in spite of their much smaller output of steam, to charge half of the extra cost of the spare to them, and the other half to the natural draught boilers.

The figures charged in Table V. as share of spare against the forced and natural draught boilers respectively have been determined thus: the quantity of water evaporated by the spare boilers is 1,563,000 gallons, at a cost of 15s. 5·8d. per 1,000 gallons; the difference in the cost of evaporating one-half of this, viz., 781,500 gallons at 15s. 5·8d., and the same quantity at 7s. 3·3d., the cost of the steam made in the forced draught boilers, amounts to £322 14s. 11d. or 11·62d. per 1,000 gallons on the quantity evaporated in the forced draught boilers. Similarly the difference in the cost of evaporating 781,500 gallons at 15s. 5·8d. and the same quantity at provisionally 9s. 2·75d. amounts to £249 4s. 6d., or 4·4d. per 1,000 gallons on the quantity evaporated in the natural draught boilers. Even if this distribution of the extra cost of the steam made by the spare boilers be heavier than it should be on the forced draught boilers, the figures will, all the same, show that a too large spare plant may prove an expensive luxury, quite apart from the fact that, unless kept in good working order and tried from time to time, it may fail in more ways than one when most required.

The Author regrets that circumstances have compelled him to confine his observations to a type of boilers not so universal as was the case a few years ago, and which work at a pressure much below that now commonly used, but he ventures to hope that the figures may be of some use as a basis of comparison, and may perhaps elicit a more complete return from a thoroughly up-to-date plant.

In conclusion the Author would express his thanks to the officials of the Company who have allowed him to use the figures, but who have expressed the wish that their names should not be made public.

TABLE SHOWING NUMBER OF BRITISH THERMAL UNITS IN

Price of Fuel in Shillings

B. Th. Units per lb. of Fuel.	5/-	6/-	7/-	8/-	9/-	10/-	11/-	12/-
10000	373300	311000	266666	233333	207407	186666	169600	155555
10200	380800	317200	272000	238000	211600	190400	173100	158600
10400	388300	323400	277300	242700	215700	194100	176500	161700
10600	395800	329700	282700	247300	219850	197900	179900	164900
10800	403300	335900	288000	252000	224000	201700	183300	167900
11000	410800	342100	293300	256700	228100	205400	186700	171100
11200	418200	348300	298700	261300	232300	209100	190100	174200
11400	425700	354600	304000	266000	236400	212900	193500	177300
11600	433200	360800	309300	270700	240600	216600	196800	180400
11800	440600	367000	314700	275300	244600	220300	200200	183500
12000	448100	373200	320000	280000	248800	224000	203600	186600
12200	455600	379400	325300	284700	252900	227800	207000	189700
12400	463000	385700	330700	289300	257100	231500	210400	192800
12600	470500	391900	336000	294000	261200	235200	213800	195900
12800	478000	398100	341300	298700	265400	239000	217200	199000
13000	485400	404300	346700	303300	269500	242700	220600	202100
13200	492900	410600	352000	308000	273700	246400	224000	205300
13400	500400	416800	357300	312700	277800	250200	227400	208400
13600	507800	423000	362700	317300	282000	253900	230800	211500
13800	515300	429200	368000	322000	286100	257600	234200	214600
14000	522800	435400	373300	326700	299300	261400	237600	217700
14200	...	441700	378700	331300	294400	265100	241000	220800
14400	...	...	384000	336000	298600	268800	244400	223900
14600	...	...	...	340700	302700	272500	247800	227000
14800	...	...	...	...	306900	276200	251200	230100
15000	...	...	...	...	...	280000	254500	233200
15200	...	...	...	...	...	...	257900	236300
15400	...	...	...	...	...	...	...	239400
15600	...	...	...	...	...	...	...	...
15800	...	...	...	...	...	...	...	...
16000	...	...	...	...	...	...	...	...

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PENNYWORTH OF FUEL OF VARIOUS QUALITIES AND PRICES.

on of 2,240 lbs.

14/-	15/-	16/-	17/-	18/-	19/-	20/-	21/-	22/-
133333	...	...	...	...	...	...	...	...
136000	126900	...	...	...	...	...	...	...
138600	129400	121300	...	...	...	...	...	...
141300	131900	123700	116500	...	...	...	...	...
144000	134400	126000	118600	112000	...	...	...	...
146600	136900	128300	120500	114100	108000	...	...	...
149300	139400	130700	123000	116200	110000	104500	...	...
142000	141900	133000	125200	118200	112000	106400	101300	...
154600	144400	135300	127300	120300	114000	108300	103100	98400
157300	146900	137700	129600	122300	116000	110200	104900	100100
160000	149400	140000	131800	124400	118000	112000	106700	101800
162600	151900	142300	133900	126500	120000	113900	108400	103500
165300	154300	144700	136200	128500	121700	115800	110200	105200
168000	156800	147000	138400	130600	123600	117600	112000	106900
170600	159300	149300	140500	132700	125700	119500	113800	108500
173300	161800	151700	142800	134700	127500	121400	115600	110300
176000	164300	154000	145000	136800	129500	123200	117300	112000
178600	166800	156300	147100	138900	131750	125100	119100	113700
181300	169300	158700	149400	141000	133500	127000	120900	115700
184000	171800	161000	151500	143100	135750	128800	122700	117100
186600	174300	163300	153700	145200	137500	130700	124400	118800
189300	176800	165700	156000	147200	139500	132500	126200	120500
192000	179200	168000	158100	149300	141500	134400	128000	122200
194600	181700	170300	160300	151400	143500	136300	129700	123900
197300	184200	172700	162500	153400	145500	138100	131500	125600
200000	186700	175000	164700	155500	147200	140000	133300	127300
202600	189200	177300	166900	157600	149100	141900	135100	129000
205300	191700	179700	169100	159600	151000	143700	136900	130700
208000	194200	182000	171300	161700	153000	145600	138600	132400
210600	196700	184300	173500	163800	155000	147500	140400	134100
...	199200	186700	175700	165800	157000	149300	142200	135800

ost of Electrical Energy ; see this Journal, 1894, vol. xxiii., p. 404A.

TABLE II.

FORCED DRAUGHT BOILERS. NOS. 1, 2, AND 3.

Date.	Boiler Time.	Fuel.					Water.				Working Expenses.							
		Breeze	Large Coke	Total.	Average price per Ton	Refuse.	Evaporated.	Used by Fan Engine.	Net Evaporation.	Evaporated per hour per Boiler.	Cost of Fuel.	Wages of Stokers and Cleaners.	Fuel Weighing and Distribution.	Removal of Refuse.	Water.	Light.	Stores.	Total.
1895	Boiler Hours.	Tons.	Tons.	Tons.	s. d.	Tons.	Gallons.	Gallons.	Gallons.	Gallons.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Jan.	1,867	515	...	515	3 6	122	715,850	46,675	669,175	358	90 2 6	23 6 11	2 4 5	12 4 0	11 18 7	2 7 0	1 5 9	53 6 8
Feb.	1,615	390	...	390	3 6	93	542,100	40,375	501,725	311	58 16 0	25 19 0	1 11 4	9 6 0	9 0 8	2 10 0	0 18 3	49 5 3
Mar.	1,265	289	...	289	3 6	140	401,710	31,625	370,085	293	50 11 6	28 17 3	1 4 5	14 0 0	6 13 11	1 0 4	1 7 4	53 3 3
April	1,866	443	...	443	3 6	102	615,770	46,650	569,120	305	77 10 6	24 14 0	2 12 3	10 4 0	10 5 3	1 11 0	1 0 4	50 6 10
May	1,927	433	19	452	3 9	102	640,174	48,174	592,000	307	84 16 0	24 1 0	2 10 3	10 4 0	10 13 5	0 15 4	1 14 6	49 18 6
June	1,315	292	...	292	3 6	95	405,880	32,875	373,005	284	51 2 0	25 1 4	0 19 9	9 10 0	6 15 3	0 13 0	1 5 9	44 5 1
July	1,855	361	99	460	4 9½	95	701,374	46,374	655,000	353	110 4 0	15 12 5	2 10 11	9 10 0	11 13 10	1 3 0	1 6 1	41 16 3
Aug.	1,994	344	138	482	5 2½	96	756,368	49,850	706,518	354	125 15 0	17 16 9	2 9 11	9 12 0	12 12 2	1 2 6	0 11 4	44 4 8
Sept.	1,903	280	140	420	5 6	85	671,440	47,575	623,865	328	115 10 0	20 4 9	1 4 10	8 10 0	11 3 10	1 2 8	0 18 11	43 5 0
Oct.	1,814	236	176	412	6 0¾	79	682,856	45,350	637,506	351	124 18 0	21 19 2	2 3 3	7 18 0	11 7 7	1 1 4	2 3 4	46 12 8
Nov.	1,338	291	12	303	3 9	92	433,030	33,450	399,580	299	84 3 6	25 4 5	1 4 7	9 4 0	7 4 4	1 5 4	3 10 11	44 2 8
Dec.	1,840	442	...	442	3 6	102	614,380	46,000	568,380	309	77 17 0	24 10 6	2 12 3	10 4 0	10 4 8	1 15 4	0 6 8	49 13 5

TABLE III.

NATURAL DRAUGHT BOILERS. NOS. 4, 5, 6, 7, 8 AND 9.

Date.	Boiler Time.	Fuel.					Water.			Cost of Fuel.	Working Expenses.						
		Welsh.	Scotch.	Total.	Average price per Ton.	Refuse.	Evaporated.	Evaporated per lb. of Fuel.	Evaporated per hour per Boiler.		Wages of Stokers and Cleaners.	Fuel Weighing and Distribution.	Removal of Refuse.	Water.	Light.	Stores.	Total.
1895.	Boiler Hours.	Tons.	Tons.	Tons.	s. d.	Tons.	Gallons.	lbs.	Gallons.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Jan.	2,351	487	...	487	14 6	47	892,320	8·18	380	353 1 6	23 8 2	2 2 0	4 14 0	14 17 6	2 19 0	0 14 3	48 14 11
Feb.	2,234	408	...	408	14 6	48	819,592	8·97	367	295 16 0	26 13 0	1 12 9	4 16 0	13 13 0	3 9 0	0 13 3	50 17 0
Mar.	2,944	536	...	536	14 6	70	1,103,084	9·18	375	388 12 0	23 17 5	2 5 4	7 0 0	18 7 8	3 11 0	2 1 4	57 2 9
April	2,296	436	...	436	14 6	49	889,596	9·11	387	316 2 0	29 19 4	2 11 6	4 18 0	14 16 6	1 18 8	0 15 1	54 19 1
May	3,034	525	...	525	14 6	54	1,098,106	9·34	362	382 12 6	16 19 4	2 18 3	5 8 0	18 6 0	1 3 8	1 13 7	46 8 10
June	3,005	492	...	492	14 6	52	1,084,922	9·84	361	356 14 0	14 16 11	1 13 4	5 4 0	18 1 7	1 10 0	1 15 1	43 0 11
July	3,135	526	86	612	14 3½	72	1,381,211	10·07	440	437 13 0	25 3 2	3 7 8	7 4 0	23 0 5	1 15 2	1 9 5	61 19 10
Aug.	3,282	587	...	587	14 6	72	1,343,916	10·22	409	425 11 6	32 4 6	3 0 9	7 4 0	22 7 11	1 17 0	0 7 8	67 1 10
Sept.	3,399	609	...	609	14 6	73	1,345,906	9·86	396	441 10 6	22 2 5	1 15 11	7 6 0	22 8 7	2 0 4	1 0 2	56 13 5
Oct.	3,409	619	...	619	14 6	71	1,360,745	9·81	399	448 11 6	31 11 0	3 5 0	7 2 0	22 13 6	2 0 0	2 17 8	69 9 2
Nov.	3,266	440	70	510	14 3½	71	1,232,619	10·80	377	364 17 0	16 8 6	8 6 1	7 2 0	20 10 10	2 11 4	3 6 7	58 5 4
Dec.	2,702	332	156	488	14 0½	66	1,035,130	9·47	383	342 18 0	25 8 9	6 0 9	6 12 0	17 5 0	2 12 0	0 2 1	58 0 7
Avgs. and Totals	35,057	5,997	312	6,309	14 5¼	715	13,594,141	9·62	388	4,553 19 6	288 12 6	38 19 4	74 10 0	226 8 6	27 7 2	16 16 2	672 13 8

TABLE IV.

Spare Boilers. Nos. 10, 11, 12, and 13.														
Date.	Boiler Time.	Fuel.			Feed Water.		Cost of Fuel.	Working Expenses.						
		Coal.	Price per Ton.	Refuse.	Evaporated.	Per hour per Boiler.		Wages.	Fuel Weighing and Distribution.	Removal of Refuse.	Light.	Water.	Stores.	Total.
1895	Boiler Hours.	Tons.	s. d.	Tons.	Gallons.	Gallons.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Jan.	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Feb.	53	25	13 0	2·3	33,600	634	16 5 0	0 10 9	0 1 11	0 4 7	0 3 7	0 11 3	0 0 9	1 12 10
Mar.	87	23	13 0	2·1	30,912	355	14 19 0	0 18 2	0 1 11	0 4 2	0 3 0	0 10 3	0 6 9	2 4 3
April	34	10	13 0	1·0	13,440	395	6 10 0	0 7 1	0 1 2	0 2 0	0 1 7	0 4 6	0 0 10	0 17 2
May	188	58	13 0	5·3	77,952	415	37 14 0	1 19 2	0 6 5	0 10 8	0 7 0	1 6 0	0 3 8	4 12 11
June	265	65	13 0	6·0	87,360	330	42 5 0	2 15 3	0 4 6	0 12 0	0 4 0	1 9 1	0 4 7	5 9 5
July	251	67	13 1	6·1	90,048	359	43 14 6	2 12 4	0 7 5	0 12 2	0 3 10	1 10 0	0 3 3	5 9 0
Aug.	683	188	13 0	17·3	252,672	370	122 4 0	7 2 5	0 19 5	1 14 8	0 11 10	4 4 3	0 2 6	14 15 1
Sept.	1,203	327	13 0	30·1	439,488	365	212 11 0	12 10 8	0 19 3	3 0 1	1 1 8	7 6 6	0 12 2	25 10 4
Oct.	1,115	288	13 0	26·5	387,072	347	187 16 4	11 12 4	1 10 4	2 13 0	0 18 8	6 9 0	1 7 11	24 11 3
Nov.	446	112	13 0¾	10·3	150,528	337	73 0 2	4 12 11	4 18 5	1 0 8	0 11 3	2 10 2	0 14 7	14 8 0
Dec.	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Avgs. and Totals	4,325	1,163	13 0⅛	107·0	1,563,072	361	756 9 0	45 1 1	9 10 9	10 14 0	4 6 5	26 1 0	3 17 0	99 10 3

Forced Draught Boilers. Water evaporated, 6,665,960 Gallons.

	£ s. d.	Costs per Annum £ s. d.	Costs per Annum pr cent.	Costs per 1,000 Galls. s. d.
Fuel Bill	...	1,051 6 0	43·22	3 1·84
Other Working Expenses—				
Wages of Stokers, &c.	277 7 6	...	...	...
Fuel Receipt	23 8 2	...	...	...
Removal of Refuse	120 6 0	...	...	...
Water	119 3 6	...	...	...
Light	16 6 10	...	...	...
Stores	16 19 2	573 11 2	23·58	1 8·65
Maintenances—				
Boilers and Mountings	24 16 1	...	...	...
Furnaces and Brickwork	21 7 0	...	...	...
Feed Water Heaters	4 9 11	...	...	...
Feed Pumps	10 2 3	...	...	...
Fan and Engine	3 7 9	...	...	...
Steam and Feed Mains	7 11 0	...	...	...
Non-Conducting Coverings	13 4 9	...	...	...
Sundries	4 1 0	88 19 9	3·66	0 3·20
Insurance—				
Boiler (Explosion)	7 17 6	...	...	...
Boiler-house and Contents (Fire) ...	4 19 4	12 16 10	0·53	0 0·46
Interest on—				
First Cost of Boilers and Machinery...	113 0 0	...	...	...
First cost of Boiler-house and Chimney	52 10 0	165 10 0	6·80	0 5·95
Depreciation—				
Boilers and Machinery	113 0 0	...	...	...
Boiler-house and Contents	26 5 0	139 5 0	5·73	0 5·02
Ground Rent	...	12 10 0	0·51	0 0·44
Rates and Taxes	...	20 0 0	0·82	0 0·72
Superintendence	...	45 15 0	1·88	0 1·64
Share of Cost of Spare	...	322 14 11	13·27	0 11·62
Totals	...	2,432 8 8	100·00	7 3·54

Natural Draught Boilers. Water evaporated, 13,594,140 Gallons.

	£ s. d.	Costs per Annum £ s. d.	Costs per Annum pr cent.	Costs per 1,000 Galls. s. d.
Fuel Bill	...	4,557 19 6	73·05	6 8·47
Other Working Expenses—				
Wages of Stokers, &c.	288 12 6	...	...	...
Fuel Receipt	38 19 4	...	...	...
Removal of Refuse	79 6 0	...	...	...
Water	226 7 8	...	...	...
Light	27 7 2	...	...	...
Stores	13 11 6	674 4 2	10·79	0 11·90
Maintenances—				
Boilers and Mountings	23 14 0	...	...	...
Furnaces and Brickwork	36 7 6	...	...	...
Feed Water Heaters	8 9 8	...	...	...
Feed Pumps	19 3 0	...	...	...
Fan and Engine	...	...	...	...
Steam and Feed Mains	14 10 0	...	...	...
Non-Conducting Coverings	27 16 0	...	...	...
Sundries	7 14 11	137 5 1	2·20	0 2·42
Insurance—				
Boiler (Explosion)	15 15 0	...	...	...
Boiler-house and Contents (Fire)	9 18 8	25 13 8	0·41	0 0·46
Interest on—				
First Cost of Boilers and Machinery	149 0 0	...	...	...
First cost of Boiler-house and Chimney	95 0 0	244 0 0	3·91	0 4·31
Depreciation—				
Boilers and Machinery	149 0 0	...	...	...
Boiler-house and Contents	47 10 0	196 10 0	3·15	0 3·47
Ground Rent	...	24 0 0	0·38	0 0·42
Rates and Taxes	...	38 0 0	0·61	0 0·67
Superintendence	...	93 8 9	1·50	0 1·64
Share of Cost of Spare	...	249 4 6	4·00	0 4·40
Totals	...	5,240 5 8	100.00	9 2·12

Spare Boilers. Water evaporated, 1,563,070 Gallons.

	£ s. d.	Costs per Annum £ s. d.	Costs per Annum pr cent.	Costs per 1,000 Galls. s. d.
Fuel Bill	...	706 10 0	58·10	9 0·46
Other Working Expenses—				
Wages of Stokers, &c.	45 1 1	...	...	...
Fuel Receipt	9 10 9	...	...	...
Removal of Refuse	10 14 0	...	...	...
Water	26 1 0	...	...	...
Light	4 6 5	...	...	...
Stores	3 17 0	99 10 3	8·18	1 3·28
Maintenances—				
Boilers and Mountings	...	...	...	...
Furnaces and Brickwork	...	...	...	...
Feed Water Heaters	...	...	...	...
Feed Pumps	...	...	...	...
Fan and Engine	...	...	...	...
Steam and Feed Mains	...	...	...	...
Non-Conducting Coverings	...	...	...	...
Sundries	...	30 15 9	2·52	0 3·84
Insurance—				
Boiler (Explosion)	11 10 0	...	...	...
Boiler-house and Contents (Fire)	1 8 0	12 18 0	1·06	0 1·99
Interest on—				
First Cost of Boilers and Machinery	100 0 0	...	...	...
First cost of Boiler-house and Chimney	75 0 0	175 0 0	14·39	2 2·87
Depreciation—				
Boilers and Machinery	100 0 0	...	...	...
Boiler-house and Contents	37 10 0	137 10 0	11·31	1 9·11
Ground Rent	...	16 10 0	1·36	0 2·53
Rates and Taxes	...	26 13 0	2·19	0 4·09
Superintendence	...	10 16 3	0·89	0 1·66
Share of Cost of Spare	...	...	...	...
Totals	...	1,216 3 3	100·00	15 5·83

All Boilers. Water evaporated, 21,823,170 Gallons.

	Costs per Annum £ s. d.	Costs per Annum pr cent.	Costs per 1,000 Galls. s. d.
Fuel Bill	6,315 15 6	67·81	5 9·43
Other Working Expenses—			
Wages of Stokers, &c.	...	...	...
Fuel Receipt	...	...	...
Removal of Refuse	...	...	...
Water	...	...	...
Light	...	...	...
Stores	1,347 5 7	14·44	1 2·82
Maintenances—			
Boilers and Mountings	...	...	...
Furnaces and Brickwork	...	...	...
Feed Water Heaters	...	...	...
Feed Pumps	...	...	...
Fan and Engine	...	...	...
Steam and Feed Mains	...	...	...
Non-Conducting Coverings	...	...	...
Sundries	257 0 7	2·76	0 2·82
Insurance—			
Boiler (Explosion)	...	...	...
Boiler-house and Contents (Fire)	51 8 6	0·55	0 0·56
Interest on—			
First Cost of Boilers and Machinery	...	...	...
First cost of Boiler-house and Chimney	584 10 0	6·27	0 6·4[illegible]
Depreciation—			
Boilers and Machinery	...	...	...
Boiler-house and Contents	473 5 0	5·08	0 5·20
Ground Rent	53 0 0	0·57	0 0·58
Rates and Taxes	84 13 0	0·91	0 0·92
Superintendence	150 0 0	1·61	0 2·04
Share of Cost of Spare	...	...	...
Totals	9,316 18 2	100·00	8 6·80

INFLUENCE OF CHEAP FUELS ON THE COST OF ELECTRICAL ENERGY

By R. E. CROMPTON, Past-President.

[illegible] worthy of the [illegible] members of this [illegible]

[illegible] the United Kingdom [illegible] experience in generating [illegible] on a large scale [illegible] put down in the [illegible] to work gas engines [illegible] cheap fuels.

[illegible] exhaustively with [illegible] coke [illegible] present paper [illegible] other important [illegible] the hope that the [illegible] our members who [illegible] electrical power [illegible] already directed [illegible] Perhaps the first and most [illegible] is the extent of [illegible] do not think that [illegible] been sufficiently looked into. [illegible] very considerable [illegible] had almost for [illegible] because the difficulties in [illegible] had thought it [illegible] Immediately [illegible] on a large [illegible] considerable importance [illegible] fix on a price [illegible] period. To enable [illegible] communi[illegible] have ascertained [illegible] Derbyshire, [illegible] available [illegible] last few years has [illegible] could in [illegible] including wagon

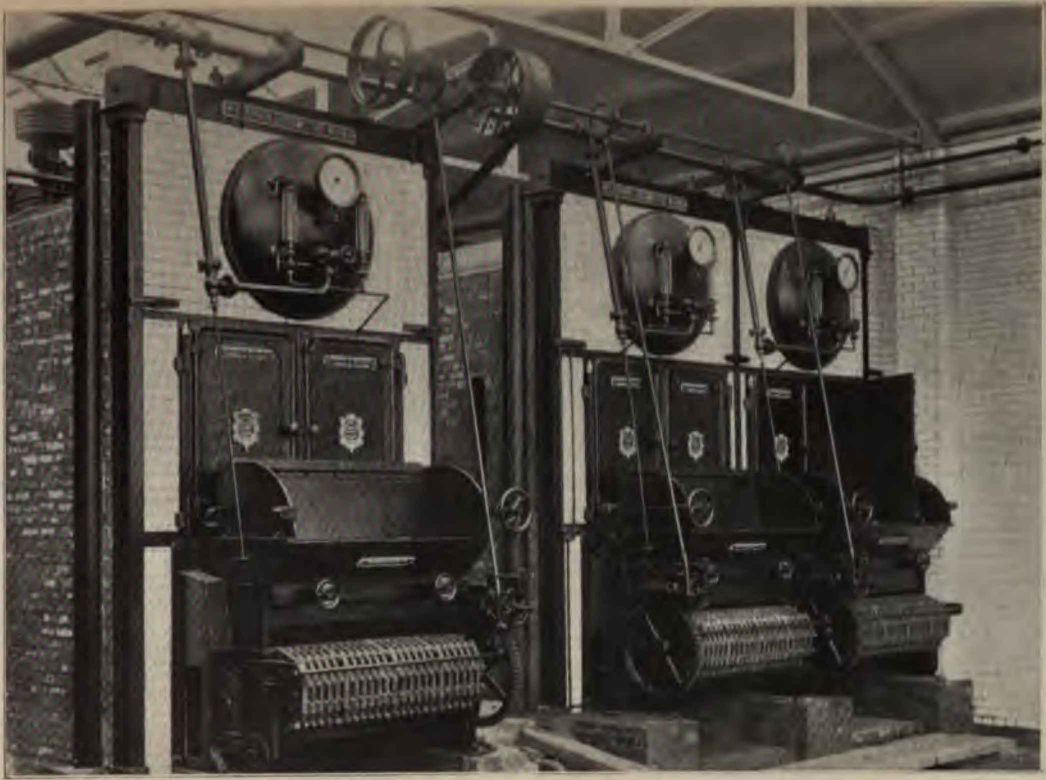

FIG. 1.—End-Elevation of Boilers fitted with Babcock & Wilcox Revolving Grate.

hire, within an average radius of fifty miles for about 5s. 4d. per ton. At the present time, owing to exceptional demand, the present price is one shilling per ton higher than this, but I am informed that this higher price is not likely to be maintained, and that it would be fair to base my calculations on the assumption that a large supply of this coal would be available at the above price.

Whilst on this subject I must point out that railway rates and wagon hire are the same for inferior as for the best quality of fuels, so that this inferior fuel cannot be delivered to distant parts of the United Kingdom, such as in the case of our own works at Chelmsford, under 14s., and it appears probable that it will rarely pay us to deal with these cheap fuels at an average radius much in excess of fifty miles from the colliery.

Where a system of canal transport is available, as in the Birmingham district, these conditions will of course be modified on account of the much lower rate for carriage and barge hire. From inquiries I have made, it is probable that the Cannock Chase class of slack may be delivered within an average radius of fifty miles from the colliery at about 5s. 6d.

There are three distinct classes of cheap fuels available for generating electrical energy. The first are those in which the calorific value is chiefly in the contained carbon. These include the anthracite and small Welsh coals, and the refuse coke fuels dealt with by Mr. Holliday. The difficulties in burning these fuels are not great. They are cheap because they are friable, easily broken up by carriage into powder, and thus there is always loss in transit; such powdered fuel is liable to fall through the bars or be carried forward in the form of dust into the flues and chimney. All easily pulverised fuel is also likely to have additional earthy matter mixed with it, as whenever a heap of it is shovelled over, the earthy bottom gets mixed with it, and thus its liability to form clinker is increased.

The second class of cheap fuel is the free-burning small coals of the Midland districts. In this class I include all the small and earthy coals which are only slightly bituminous and which therefore have slight tendency to cake.

The third class is the *small and dirty* or earthy caking or *bituminous coals of the North.* These last are the most

difficult to deal with, but as they possess high calorific value the problem of dealing with them successfully is the most interesting of all.

The first group of fuels have been burned, with considerable success, by several forms of furnaces in addition to those described by Mr. Holliday. In this class it is all-important to reduce as far as possible the loss of unburnt fuel by its falling through the fire bars or being carried forward into the flues in an unconsumed condition. So far probably the best method of dealing with the clinker from this class is the provision of large water ash pans, the steam rising from which appears to have the effect of preventing the clinker from clinging to the bars. A great portion of it separates as it forms into small drops of melted matter and falls through the bars into the water instead of forming large cakes which hinder the air-admission.

Up to the present the attempts to deal satisfactorily with the second and third classes of fuels have been chiefly connected with the use of automatic appliances for distributing the fuel over the bars, breaking up and getting rid of the clinker, and providing sufficient admixture of air at various points in the furnace to insure satisfactory combustion of the gases. These last difficulties are at their greatest where a great portion of the calorific value of the fuel lies in its volatilisable products.

I think that most of us who have had experience in the use of automatic stokers will agree with me that although in some cases where a large range of boilers has been automatically fired, economies in labour have undoubtedly followed, yet the cost of clinkering the grates and afterwards removing the clinker from the boiler-room and the cost of maintenance of the grates and furnaces has been so considerable, and these difficulties and costs increase so rapidly with the amount of ash present in the fuel, that in most cases even with these automatic stokers it has been advisable not to use the very cheapest class.

With the third, or highly bituminous class, coking stokers have been used with more or less success. Most of these operate on the principle of spreading the coal on the front end of the grate, allowing it sufficient time to form itself into coke, and then by means of moving bars to break up and move this coke forward over the bars up to the point where

intense combustion and radiation is required. This method is correct in theory, but it has not worked out well in prac-

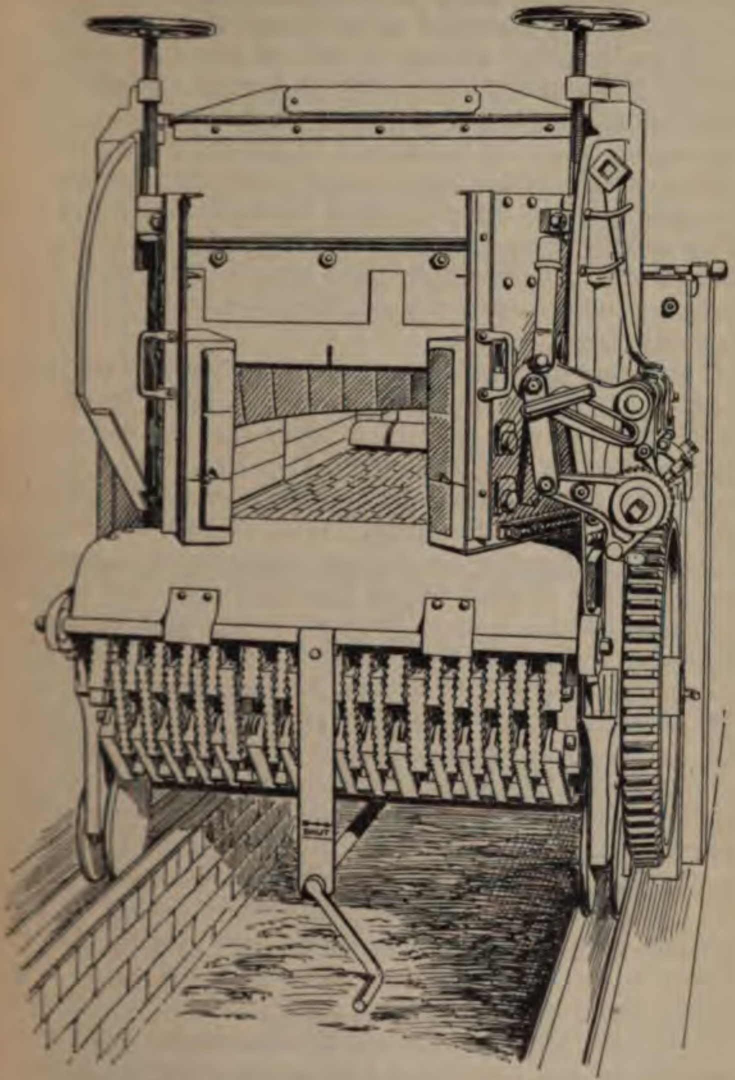

FIG. 2.—Front View of Babcock & Wilcox Revolving Grate.

tice. The moving bars do not move the caked material forward with sufficient regularity, so that openings occur in the fire, and thus excess of air is allowed to dilute the gaseous

heated products of combustion, and their temperature is thereby reduced. Clinker is seldom automatically got rid of, and in most cases a considerable amount of hand labour has to be expended on its loosening and removal.

From the above remarks it will be seen that one great difficulty in burning cheap fuels at a small cost for labour and maintenance is that of getting rid of the clinker. What we require is that the fuel should be tipped from the railway trucks or barges into conveyers and thence distributed to the furnaces without being touched by the firemen, and that after passing through the furnace the clinker and ashes should also be automatically taken away from the back of the furnaces and delivered into a railway truck without any hand labour being necessary.

There are two distinct methods of dealing with the cheap fuels which contain much volatilisable matter. The first is that described very fully in a paper read on the 16th of March, 1897, by Mr. Humphrey (vide *Min. Proc. Inst. C.E.*, vol. cxxix. p. 190) before the Institution of Civil Engineers on the Mond Gas Producer. With this system the fuel is gasified in separate gas producers and the gas then burnt under boilers or used in gas engines. I do not propose to deal with this system, although it may well be a most satisfactory way of utilising cheap fuels, as it has been most thoroughly described by Mr. H. A. Humphrey in his paper. He showed that by this method 90 lbs. of sulphate of ammonia, which represents about 70 per cent. of the total nitrogen in the fuel, may be recovered from it, and that the gas from each ton of coal is then capable, under ordinary boilers, of evaporating not less than seven tons of water. The repairs and up-keep of the system appear to be satisfactorily low.

I propose for the present to confine myself to suggestions as to the form of furnace which may be attached direct to the boilers to burn these inferior fuels so as to evaporate the water at the least cost.

Mr. Holliday has called our attention to the fact that in considering such furnaces and the boilers best suited to them, the use of cheap fuel has undoubtedly up to the present necessitated the use of larger furnaces and larger boiler plant, so that there has been considerable increase in the capital cost and hence in the maintenance charges which are a percentage of that cost, and this of course increases the real cost

per 1,000 gallons of water evaporated. I think, however, that in the case of externally fired boilers at any rate, arrangements may be suggested by which the grate-area only need be increased, the size of the boiler remaining the same as for the best fuel; for if we so arrange our grate that those portions of it in which the preliminary work of igniting and caking the fuel is performed are at a comparatively low tem-

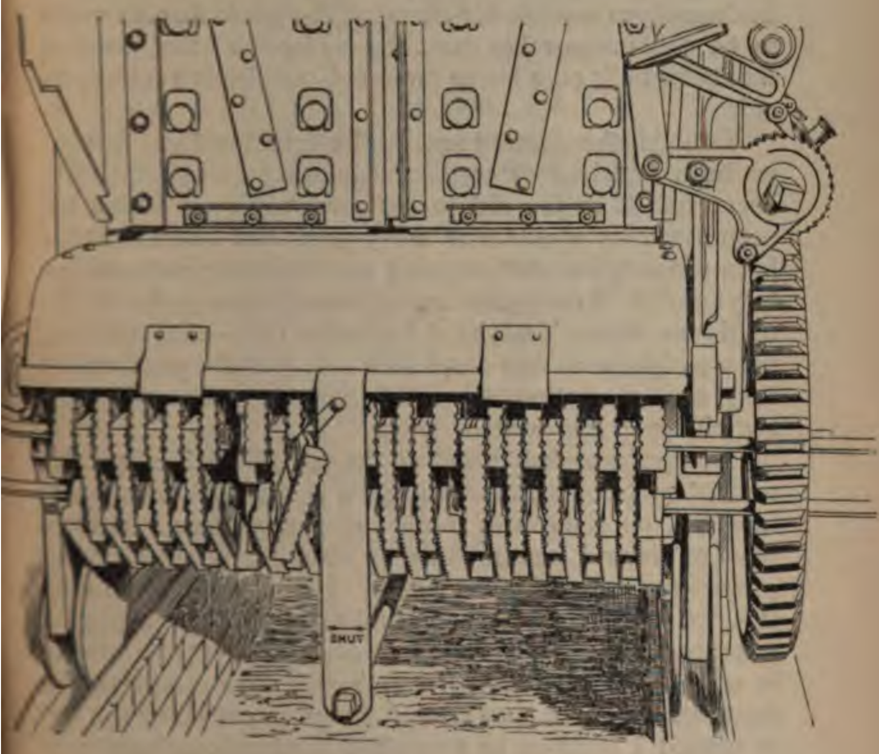

FIG. 3.—Front View of Babcock & Wilcox Revolving Grate.

perature, this portion of the grate or furnace may be exterior to the boiler, and it follows that the part of the furnace in which advanced combustion is carried on would be no larger than would be the case if we were burning the very best Welsh coal; but it is only fair to say that in the case of bituminous fuels where it is necessary to prevent newly formed volatilisable products from coming into contact with the cold boiler surfaces considerable additional space will

have to be provided exterior to the boiler itself, as it is evident that in this case in order to produce perfect combustion of these products some form of combustion chamber which contains a large surface of highly incandescent material must be provided. Again, however carefully we may provide for the disposal of the clinker, portions of it are certain to adhere to the bars and lining of the furnace or combustion chambers, and in order that these parts may be made easily accessible for cleaning, the whole furnace ought to be easily removable from the boiler—in other words, it should be built on a frame mounted on wheels running on rails.

Probably the simplest and most efficient method that has yet been contrived of continuously firing a large grate with cheap fuel is by the old Juckes revolving grate which has been in use for upwards of thirty years, and wherever it has been properly installed and well mounted has given satisfactory results. I remember seeing one of these grates in use in Messrs. Fowler's works at Leeds in 1871—that is to say, twenty-eight years ago—and I am told that the performance has been so continuously satisfactory that Messrs. Fowler are still using this form of grate.

It appears probable that all the conditions I have above noticed could be satisfactorily filled up by a revolving grate mounted on a movable frame running on rails. In these days of electric motors there is no difficulty in providing power for working this grate. It can easily be constructed to deliver the clinker and ashes continuously into a transverse channel at the back end of the grate, whence it could be removed by a conveyer to suitable trucks. Immediately above that part of the grate on which the fuel is ignited I propose to provide a combustion chamber in the form of a long bridge made of a special quality of firebrick. I have found by experiment that a good way of arranging this apparatus is in the form of an extended firebrick arch, each arch-shaped brick having a fin-like projection hanging down from its lower surface into the path of the gases. I have already used this form of combustion chamber for Lancashire boilers at our works at Chelmsford with satisfactory results. The extended surface of firebrick acts extremely well as a reservoir of heat even under the difficult circumstances of firing a Lancashire boiler the

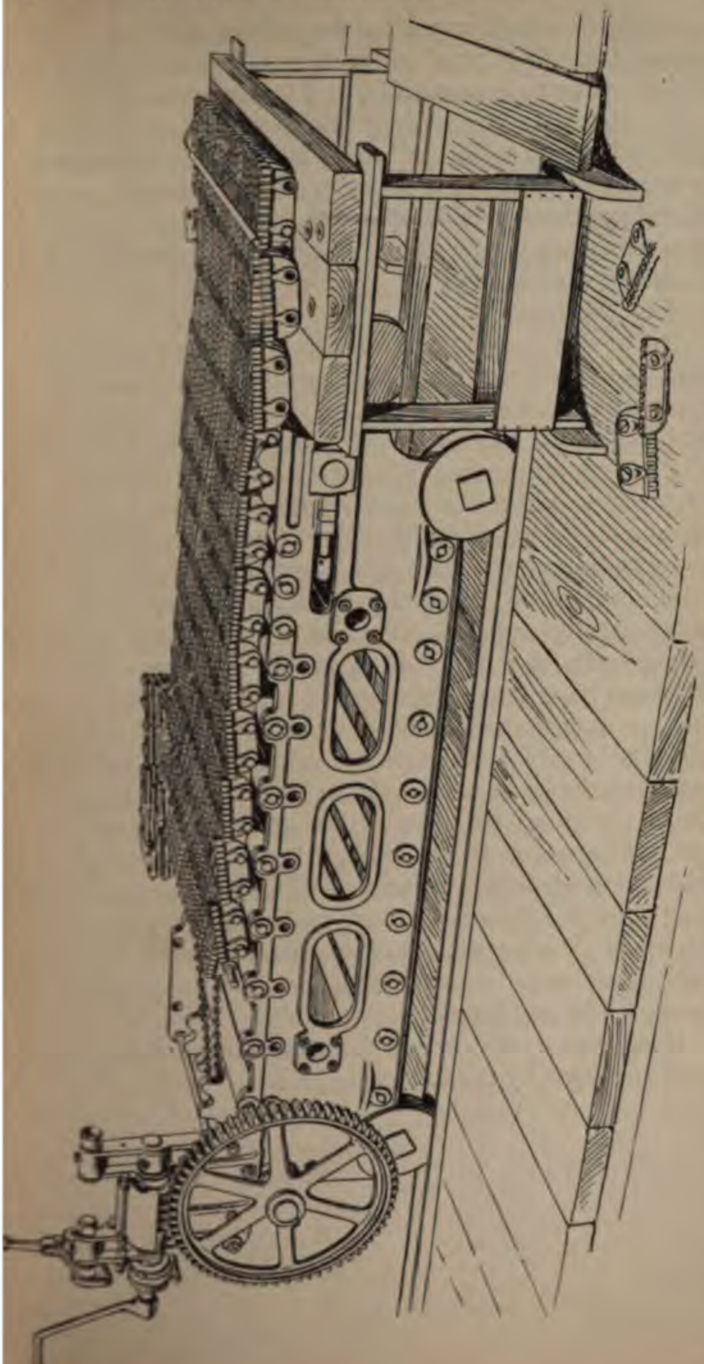

FIG. 4.—General View of Babcock & Wilcox Revolving Grate.

fire door of which must be frequently opened, but it is evident that this form of bridge will work much more efficiently in an automatically, and hence continuously fired, boiler where no necessity exists for so often opening the door and hence admitting cold air. As I have pointed out above, for burning the first group of cheap fuels this regenerative apparatus may be dispensed with. It is somewhat more necessary in the case of the second group, but it is absolutely necessary in the case of the bituminous smoky fuels of the third group.

Up to the present the weak point of smoke-consuming apparatus has been that it has generally stopped short at supplying additional air so as to obtain more perfect combustion of the fuel, and although this has resulted in a larger proportion of the CO being converted into CO_2, yet as this has been effected by passing a considerable excess of air through the furnace, the heated products have been so diluted and cooled that not only is the output of the boiler diminished, but also its efficiency greatly reduced. The only satisfactory method of dealing with the question is to provide the combustion chamber I have above described. I need hardly remind those who are accustomed to boiler tests that the efficiency of a boiler is largely proportionate to the proportion of CO_2 present in the gases as they leave the furnace. On tests we always try to get this proportion as high as possible. In my experiments at Chelmsford, I have been able when my combustion chambers were worked successfully, and when using highly bituminous fuel, to bring the proportion of CO_2 up to 11 per cent., which is sufficient proof that a very small excess of air was passing, and that the products were consequently undiluted.

How important it is that the excess of air should be kept down is shown by the following table.

	Test of water-tube boiler at St. Pancras.		Test of water-tube boiler at Glasgow.		Result of the Glasgow test if excess of air had been prevented.	
	B.T.U.	Per cent.	B.T.U.	Per cent.	B.T.U.	Per cent.
Heat transferred to water	10,463	72·6	8,228	68	9,960	83
Heat carried off with products of combustion and excess air	1,792	12·4	2,959	25·25	1,440	12
Heat in unburnt fuel mixed with ashes ...	316	2·2	417	3·45	240	2
Heat radiated and otherwise unaccounted for	1,829	12·7	390	3·22	360	3
B.T.U. in fuel	14,400	100	12,012	100	12,000	100

In column 1 I give the figures of an often-quoted test made with a water-tube boiler using the best Welsh coal, hand-fired. In this case only about 12·5 per cent. of the heat was carried off with the products of combustion and excess air. Owing probably to considerable radiation losses the efficiency of the boiler in this case was not extremely high, being under 73 per cent. In column 2 I give the results of a test made at Glasgow with a water-tube boiler, coal having a calorific value of 12,000 B.T.U., being fired by automatic stoking apparatus. From the inefficient working of this apparatus it was found difficult to keep the bars properly and evenly covered, so that what otherwise would have been an extremely good result was spoilt, as the heat losses due to heat carried off with the products of combustion and by excess air were over 25 per cent., so that the total efficiency therefore worked out at only 68 per cent. In column 3 I give the results that ought to have been obtained at this test with automatic stoking of this class of fuel if this excess of air had been properly controlled.

Since I commenced the preparation of this paper I have learnt that the Babcock & Wilcox Co., who have already done so much to reduce the cost of steam raising, have actually perfected and brought into practical use a form of furnace which combines a considerable number of the requirements that I have laid down in this paper as necessary for the satisfactory and economical burning of cheap fuels. *In the Babcock & Wilcox* new revolving grate,

illustrated by Figs. 1, 2, 3, and 4, it will be seen that they provide a modern revolving grate which performs the duties of feeding the fuel on to the front of the grate and delivering the ashes and clinker at the back of the grate in a most satisfactory manner. The whole grate is mounted on a removable frame running on rails so that it can be removed from the furnace and ready access given to the parts for examination, renewal, or repair. The difficulty of getting rid of the clinker and ashes at the back of the grate without admitting air at this point was a matter in which the old Juckes grate was defective. This is got over by means of a very heavy cast-iron flap which rests on the revolving bars at their back end. The bars have to move forward under this flap, and as it has a sharp edge the clinker and ashes are removed from the bars, slide over its inclined surface, and are delivered into an air-tight receptacle at the back whence they can be removed by a conveyer or other convenient means. It is probable that this revolving furnace is a great step in advance, and probably the only addition that is required to perfect it is the addition of the combustion chamber which I have described and which is illustrated in Fig. 5.

In order to show the proportion the cost of fuel bears to the total cost of generating energy in a modern power station of moderate size I have extracted figures from the log book of the power station of our new Chelmsford works, from which I have prepared the accompanying table, which shows that under the actual conditions of working the plant during the last forty-nine weeks, and at an average price of 17s. 5d. per ton of coal (which was Nottinghamshire steam hard of the best quality), the cost of the fuel was 64 per cent. of the total cost of 0·77d. per B.O.T. unit delivered to the tools. This plant is of moderate size; including spares, its maximum rate of output at present is about 250 kwts. It is not easy to give the average rate at which it is worked, but it is probable that this is at the rate of about 120 kwts. during 54 hours per week and 50 kwts during the night shift during 62 hours per week. If the plant had been worked at the higher rate throughout the night as well as the day shift, the output would have been increased from 368,000 B.O.T. units to 680,000 B.O.T. units, and the cost prices would have been modified as in the second column, that is to say that the cost

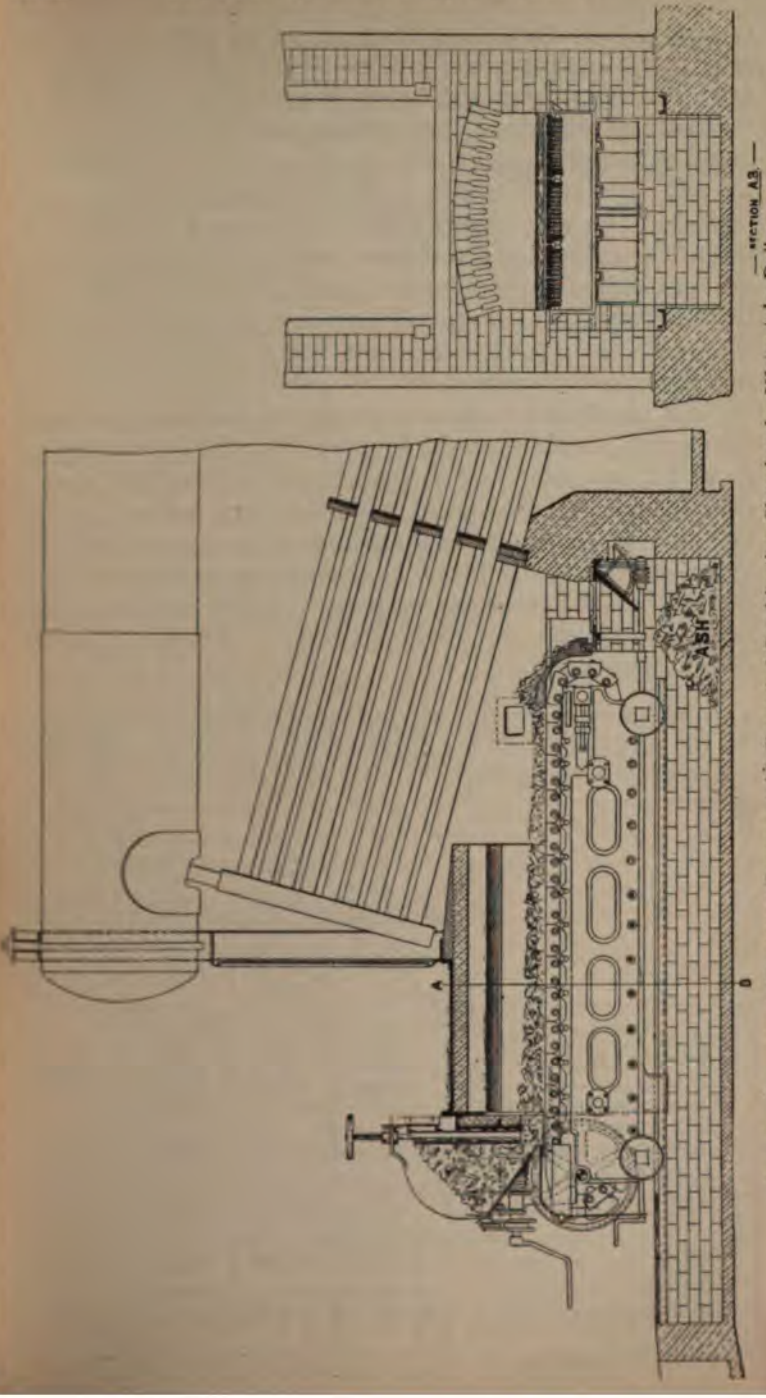

FIG. 5.—Crompton's Proposed Furnace with Extended Combination Chamber for Water-tube Boilers.

of coal would then have been about 76 per cent. of the total cost, which would stand at 0·632d. per unit. If, however, this plant were put to work within the radius of 50 miles from collieries where cheap coal at 5s. 4d. per ton could be supplied and the furnaces of the boilers modified to suit this fuel in the manner I have indicated, the figures in the 3rd column would be obtained at the rate of output in column 1; and those in the 4th column at the rate of output in column 2, and it must be observed that in these two columns I have not reduced the cost of labour to the extent that might fairly be claimed by the saving in stokers' wages.

It is needless for me to point out to you that increasing the size of this plant would largely reduce the labour charge, so that it is probable that (exclusive of interest and depreciation) the total cost price of one farthing per unit would be reached in many cases, providing that the coal obtainable at 5s. 4d. per ton is burnt in a satisfactory manner. The fact that such figures are now easily within reach ought to be a powerful stimulus to the investment of capital in power distribution works.

TABLE SHOWING THE PROPORTION WHICH THE COST OF FUEL BEARS TO THE TOTAL COST IN CHELMSFORD NEW WORKS POWER STATION.

	(1)	(2)	(3)	(4)
	Actual cost per B.O.T. unit at output of 368,000 units in 49 weeks.	Calculated cost if full night shift be worked, giving 580,000 units in same period.	Cost as in col. 1 if coal 5s. 4d. per ton were available.	Cost as in col. 2 if coal at 5s. 4d. per ton were available.
	d.	*d.*	*d.*	*d.*
Coal at 17s. 5d. per ton delivered at boilers ...	0·488	0·480	0·15	0·148
Stores	0·0293	0·016	0·0293	0·016
Labour, superintendence, two complete shifts, including flue and boiler cleaning	0·236	0·127	0·236	0·127
Repairs	0·016	0·009	0·016	0·009
Total	0·769	0·632	0·431	0·300
[illegible]l to total cost	64 %	76 %	35 %	49 %

ADDENDUM.

Test made since the reading of the paper of a Babcock & Wilcox water-tube boiler fitted with the revolving grate described in the paper.

Heating surface	Sq. ft.	1827
Grate surface (7' 0" long × 5' 0" wide) chain-grate stoker	„	35
Ratio of heating surface to grate surface ...	Ratio	1 : 52·4
Kind of fuel used	Kind	Boodyke Singles
Duration of test	Time	6 hours.
Average observed gauge pressure (atmospheric pressure 14·7)	Lbs.	166·25
Average temperature of water fed by boiler, by feed pump	Deg.	50
Pounds of fuel fired (dry)	Lbs.	4032
Pounds of fuel fired per hour	„	672
Pounds of refuse	„	318·5
Pounds of combustible	„	3713·5
Coal consumed per sq. ft. of grate per hour	„	19·2
Total water evaporated (actual conditions)	„	27150
Water evaporated per hour „ „	„	4525
Water evaporated per hour from and at 212° factor 1·218	„	5511·45
Temperature of saturated steam	Deg.	373
Temperature of superheated steam	„	453
Superheat	„	80
Water evaporated per sq. ft. heating surface per hour	Lbs.	2·47
Water evaporated per lb. of coal, actual conditions (feed water 50° Fahr., steam pressure 166·25 lbs.)	„	6·73
Condition of coal		Very wet.
Water evaporated per lb. of coal, assuming feed water at 212° and under atmospheric pressure. Factor, 1·218 ...	„	8·197
Water evaporated per lb. of combustible, actual conditions (feed water 50° Fahr., steam pressure 166·25 lbs.)	„	7·31
Water evaporated per lb. of combustible, assuming feed water 50° Fahr. and steam pressure 166·25 lbs. Factor 1·218 ...	„	8·90
Temperature of boiler rooms	Deg.	70
Temperature of flue gases	„	524
Force of draught in inches of water... ...	Inches	0·184
Calorific value, theoretical evaporation from and at 212°	Per lb.	11·33
Efficiency heat utilised in boiler	Per cent.	72·34
Efficiency heat utilised in superheater ...	„	2·21
Total efficiency	„	74·55

of coal would then have been about 76 per cent. of the total cost, which would stand at 0·63d. per unit. If, however, this plant were put to work within the radius of 50 miles from collieries where cheap coal at 5s. 4d. per ton could be supplied and the furnaces of the boilers modified to suit this fuel in the manner I have indicated, the figures in the 3rd column would be obtained at the rate of output in column 1; and those in the 4th column at the rate of output in column 2, and it must be observed that in these two columns I have not reduced the cost of labour to the extent that might fairly be claimed by the saving in stokers' wages.

It is needless for me to point out to you that increasing the size of this plant would largely reduce the labour charge, so that it is probable that (exclusive of interest and depreciation) the total cost price of one farthing per unit would be reached in many cases, providing that the coal obtainable at 5s. 4d. per ton is burnt in a satisfactory manner. The fact that such figures are now easily within reach ought to be a powerful stimulus to the investment of capital in power distribution works.

TABLE SHOWING THE PROPORTION WHICH THE COST OF FUEL BEARS TO THE TOTAL COST IN CHELMSFORD NEW WORKS POWER STATION.

	(1) Actual cost per B.O.T. unit at output of 368,000 units in 49 weeks.	(2) Calculated cost if full night shift be worked, giving 680,000 units in same period.	(3) Cost as in col. 1 if coal 5s. 4d. per ton were available.	(4) Cost as in col. 2 if coal at 5s. 4d. per ton were available.
	d.	*d.*	*d.*	*d.*
Coal at 17s. 5d. per ton delivered at boilers ...	0·488	0·480	0·15	0·148
Stores	0·0293	0·016	0·0293	0·016
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Repairs	0·016	0·009	0·016	0·009
Total	0·769	0·632	0·431	0·300
Coal to total cost	64 %	76 %	35 %	49 %

[redacted]

ADDENDUM.

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Ratio of heating surface to grate surface ...	Ratio	1 : 52·4
Kind of fuel used	Kind	Boodyke Singles
Duration of test	Time	6 hours.
Average observed gauge pressure (atmospheric pressure 14·7)	Lbs.	166·25
Average temperature of water fed by boiler, by feed pump	Deg.	50
Pounds of fuel fired (dry)	Lbs.	4032
Pounds of fuel fired per hour	„	672
Pounds of refuse	„	318·5
Pounds of combustible	„	3713·5
Coal consumed per sq. ft. of grate per hour	„	19·2
Total water evaporated (actual conditions)	„	27150
Water evaporated per hour „ „	„	4525
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Water evaporated per sq. ft. heating surface per hour	Lbs.	2·47
Water evaporated per lb. of coal, actual conditions (feed water 50° Fahr., steam pressure 166·25 lbs.)	„	6·73
Condition of coal		Very wet.
Water evaporated per lb. of coal, assuming feed water at 212° and under atmospheric pressure. Factor, 1·218 ...	„	8·197
Water evaporated per lb. of combustible, actual conditions (feed water 50° Fahr., steam pressure 166·25 lbs.)	„	7·31
Water evaporated per lb. of combustible, assuming feed water 50° Fahr. and steam pressure 166·25 lbs. Factor 1·218 ...	„	8·90
Temperature of boiler rooms	Deg.	70
Temperature of flue gases	„	524
Force of draught in inches of water... ...	Inches	0·184
Calorific value, theoretical evaporation from and at 212°	Per lb.	11·33
Efficiency heat utilised in boiler	Per cent.	72·34
Efficiency heat utilised in *superheater* ...	„	**2·21**
Total *efficiency*	„	**74·55**

Analysis of Coal.

Proximate Analysis.

		Per cent.	
Volatile matter	Gas tar, &c.	33·48	
	Sulphur	·55	46·78
	Water	12·75	
Coke	Fixed carbon	45·20	
	Sulphur	·61	53·22
	Ash	7·41	
			100·00

Specific gravity	1·30
Weight of one cubic foot in lbs.	81·25
Heating power, practical (lbs. of water at 212° Fahr. evaporated by 1 lb. coal), by Playfair's formula	6·90

Ultimate Analysis.

Carbon	63·43
Hydrogen	4·03
Oxygen	9·70
Nitrogen	1·52
Sulphur	1·16
Ash	7·41
Water	12·75
	100·00
Heating power, theoretical (lbs. of water at 212° Fahr. evaporated by 1 lb. coal)	11·33
Heating power of dried coal by Thompson's calorimeter	12·87

(Signed) Tatlock & Thomson.

TEST ON No. 4 BOILER. *November* 17, 1899.

Analysis of Flue Gases by Orsat's Apparatus.

The average of numerous tests on the above-mentioned apparatus at an average draught of 0·184 inches have given :—

	12·35	per cent.	CO_2
	7·25	„	O
	0·15	„	CO
and	80·25	„	N

If ordinary air is taken to contain 20·6 per cent. oxygen, the excess of air will be 50 per cent. over the theoretical quantity required.

By calculation on above data and the temperature of the flue gases compared with the temperature of boiler-house, a loss of 1375·66 B.T.U. — 12·5 per cent. is shown. The calorific value of the fuel used has been found to be, by application of chemical analysis made by R. Tatlock & Thomson in Glasgow to Dulong's formula equal

Heat Balance.

Heat used for evaporation of water	7884·4 B.T.U.	72·34 per cent.
Heat used for superheat of steam ...	242·8 „	2·21 „
Loss in flue gases per calculation,* as indicated above	1375·66 „	12·51 „
Loss unaccounted for by radiation, incomplete combustion, ashes, etc.	1486·14 „	12·94 „
	10989·00 B.T.U.	100·00 per cent.

Total efficiency ... ... 74·55 per cent.

Mr. S. Z. de Ferranti: The two papers which have been read to-night are of great interest to this Institution, principally because its members have to deal with the generation and supply of electrical energy; and, to my mind, quite the most difficult problem in the supply of electrical energy is that of steam generation. The time of year at which these papers have been read is especially suitable for emphasising this point, as it is now, unfortunately, that many central station engineers realise what a very difficult problem that of steam generation really is. Not only have we to arrange for generating the steam economically throughout the year, but to provide for times when, owing to unexpectedly large demand, from fogs in a city like this, and other causes, the steam generating-plant is very hard pressed. I think I am right in saying that where difficulties exist in electric supply, the greatest to-day is that of generating sufficient steam at the right time for running the engines. Mr. Ferranti.

The question of fuel has been largely dealt with to-night in the papers, but, owing to the large amount of coal taken by the Government, there is throughout the country—and more especially in London —a very great difficulty at present in obtaining coal of the desired class for forcing the boilers to their maximum capacity. With regard to cheap fuels, we have found at our own works, in generating electric supply for power and lighting, that we gain considerably by using very cheap fuels as compared with fairly good ones. We have no cost of getting rid of clinker, and our conditions are in that respect different from those in ordinary towns; but the difficulty which arises with us is, that so soon as we have been running for a few months with a satisfactory and cheap fuel, and made a saving, the supply of that fuel becomes exhausted, or its price is raised, so that really nothing is gained by the experiments made to find out which was the most economical in use.

With regard to economy and continuity of working, it is very important to have a sufficiently large combustion chamber. The great difficulty, especially in boilers which are forced considerably, appears to be that the hot flame impinges directly upon a cool surface, and so combustion is not as complete as it should be. The plan Mr. Crompton has shown in the diagram of his special form of incandescent arch for assisting combustion must, undoubtedly, give a very much higher

Mr. Ferranti. economy. My own experience, unfortunately, has been that the bricks of any kind of arch, even the side lining of furnaces with boilers which have a good deal of work to do, slag down very rapidly; in fact the furnaces of many electric boilers at certain times are very much like blast furnaces, the heat is so great, and the fire so intense. Although the results are very good as long as the brickwork lasts, the greatest difficulties are met with in its maintenance and in the cost of renewal.

A very vital point in the economy of steam-generation in large plants is to have sufficient spare. It is no use to have sufficient spares in the summer time; the important thing is to have a substantial spare at the worst time of the year, so that thoroughly efficient cleaning operations can go on all the year round. Most of us know of tests which have shown how quickly the efficiency of a boiler goes down as it is kept in continuous work. There is the deposit inside the boiler and there is the deposit of a coaly nature outside the boiler, that is to say on the surfaces which are exposed to the flame, and these together so effectually insulate the fire from the water that very great loss of economy results therefrom. I therefore think that one of the essential points in ensuring good economy is to have a sufficient reserve to be able to work the boilers economically, and to be able to clean them most systematically and thoroughly at all times of the year.

Mr. Stromeyer. Mr. C. E. STROMEYER: Mr. Holliday's paper is especially interesting on account of the very exact figures and details which he gives. Mr. Crompton's paper is of particular interest as being suggestive; and there are many points that one would like to discuss. Mr. Holliday's paper is rather difficult to speak upon, because it is so complete in itself, but I have made a few comparisons which may be of interest. For instance, it appears that the moving of the refuse in his case costs about 2s. per ton. The paper also shows that with coals containing much refuse matter, the efficiency of the fuel is below what it should be if reckoned by the amount of carbon and hydrogen in it, because the ash in the coal has a greater deteriorating effect than it should have theoretically—I think it is about 40 or 50 per cent. more. Taking that into account, the figures which Mr. Holliday has given work out very well. I have also calculated the cost of firing coal having different percentages of ash. If the coal were perfectly free from ash, the cost of stoking at these works would be about 1d. per ton of water evaporated; if there were 10 per cent. of ash it would be 1¼d.; with 20 per cent. it would be 2¼d.; with 30 per cent. it would be 4¼d. So that with 30 per cent. of ash in the coal the cost of firing it is increased more than fourfold. This comparison should be borne in mind in dealing with colliery proprietors as to the purchase of coal.

It is quite true, and most natural, as Mr. Crompton has said, that as soon as a demand springs up for slack the price rises. The shale oils of Scotland, which were at one time very cheap, afford another instance of this effect. Three attempts have, I believe, been made to use this shale oil for boiler purposes in steamers, and in every case the attempt had to be given up because the price of the shale oil at once increased, and it was then uneconomical to use it. The oil-burning furnaces had to be taken out and ordinary grates substituted again.

With regard to Mr. Crompton's table on page 71, giving a comparison between the two water-tube boilers, the loss of heat by radiation and in other ways, which is of course found by difference, amounted in one case to 12·7 per cent., and in another to 3·22 per cent. If those two boilers were similar, there would appear to be something wrong with the figures quoted, especially as the second is rather low. I believe the true explanation is that the amount of heat carried away by the gases is wrongly stated, for I do not believe that 25 per cent. was lost in this way. The error is very likely due to the method used for sampling the gases, a point upon which I have collected information. I should first explain, however, in what way the quantity of flue gases can be estimated. One method is by analysing the gases, and thus finding out the quantity of carbonic acid present in them; from that may be calculated the ratio between the coal used and the flue gases, and hence the quantity of gas passing through the furnace. Another method, which I believe to have been first indicated by Professor O. Reynolds, is to ascertain the quantity of heat abstracted by the Economiser. The amount of heat taken up by the economiser and that lost by the gases must be equal. They can be measured by the fall of temperature in the one case, and by the rise of temperature in the other. The weight of the feed-water is known, and therefore the weight of the gases can at once be found. I have compared the two methods in ten trials made on the same boilers, and carried out by two independent engineers. The highest result for the economiser system was 26 per cent. above, the lowest exactly 26 per cent. below, that by the gas analysis system. The two methods are therefore uncertain to the extent of $\pm$ 26 per cent., which is a very large error. The other figures are these, + 26, + 17, + 13, + 9, + 9, + 7, + 6, − 1·3, − 7, and − 26 per cent. The average result is that the economiser gives 26 lbs. of waste gases per pound of fuel, and the chemical analysis gives 25¼ lbs. The general average is thus in fair agreement, but the discrepancies are enormous, and for that reason I do not feel inclined to attach great importance to either method of determining the quantity of gases. The whole subject requires very careful investigation. Mr. Longridge, in some experiments which were in a way rather discouraging, has observed a great difference of temperature between the top and the bottom of the flue, and we do not know with certainty what is the mean temperature of the issuing gases. I also think there is considerable discrepancy in the chemical composition, according to whether the sample is taken from the top or the bottom of the flue. Mr. Stromeyer.

Mention was made in the paper of converting the fuel into gas, and the Mond system was referred to. I believe that at present that system is the most successful one, but as this process was invented specially (and is very suitable) for the production of ammonia, it does not always work when there is insufficient nitrogen in the coal. Indeed, I believe it will not always work even when the nitrogen analysis is satisfactory. There appear to be certain coals which will work with it, and certain others which will not. As soon as it is found which qualities will give the best results with that system, or in fact any other system, the price

Mr. [illegible] [illegible] will [illegible] of steam, whether you use slack or not. There will [illegible] there a saving is effected, but the [illegible] the latter.

[illegible] commend [illegible] internally fired boilers for the reason [illegible] grate may be used. I quite agree that this [illegible] advantage, [illegible] internally fired boilers have always been [illegible]. The [illegible] of that type is the egg-ended boiler, [illegible] crack as the scale settles down to the [illegible] always [illegible], and may lead to very serious explosions [illegible] in the case of twelve boilers which exploded at [illegible]. The other extreme of the externally-fired boiler is, of course, the water-tube boiler. These boilers are infinitely safer than those [illegible] but they present the same difficulty, namely, that [illegible] on the surface which is directly over the fire and [illegible] there. We find [illegible] experience that the members of the Manchester Steam Users' Association dislike them, and those who have used them are not very fond of them. They are accustomed to the Lancashire boiler, which works for many years without giving [illegible] trouble. There may occasionally be a sign of leakage, and [illegible] at the end of the week, the boiler-maker [illegible] and there is no serious trouble. But with a water-tube boiler the case is different: as soon as there is any leakage the [illegible] does not know whether the tube will burst or not, or whether something may happen, and so the boiler is at once put out [illegible] repaired. Although the cost in either case may be about the same, the [illegible] find a practical difference: in the one case they [illegible] work quietly until the end of the [illegible], whilst in the other case the boiler has [illegible] and the whole mill is thrown out of gear. I am [illegible] manufacturer's point of view. With Corporations and [illegible] large Electrical Syndicates, that point does not [illegible] have spare boilers, and if one [illegible] start another in its place. In [illegible] with a very large allowance of [illegible] as Mr. [illegible] has rightly pointed out. This is a very [illegible] and where reserves do exist, of course [illegible] two boilers are under repair or not. That [illegible] benefit of having the grates out- [illegible]. The brick arch which has also been [illegible] which Mr. Ferranti has mentioned, [illegible] aggravates the danger of which I have [illegible] point which I wish to emphasise; the heat [illegible] fired boilers are apt to suffer very much [illegible]. I believe that a very fair combination of [illegible] dry-back boilers, as they are called, [illegible] effected inside the furnace. The first [illegible] with the furnace plates, and then there [illegible] combustion chamber where all the smoke gets consumed, and then the gases are turned into the boiler tubes, so that the heat is abstracted from them.

r. Dugald Clerk: Mr. Holliday's paper is exceedingly interest- Mr. Clerk.
and it would be very valuable to engineers if more of us were to he trouble to compile statistics of the kind that he gives from the s in our charge. With regard to Mr. Crompton's paper, however, uld like to raise a note of warning against two or three things n he has suggested. In the first place, so far as I understand the r, it is quite a mistake to think that a gas producer will ever do ood in connection with a steam boiler. With the special Mond icer there are reasons why some success should be achieved; but tempts to arrange producers so as first to convert the fuel into gas hen to burn it under a steam boiler have failed, although many attempts have been made. They have failed for a reason that may ry easily understood. If you wish to convert a pure carbon fuel gas—and, of course, the majority of fuels contain a very large pro- on of carbon—you must first convert the fuel into carbonic-oxide, hen convert the carbonic-oxide into carbonic acid in the fire. The quence of this arrangement is that, if the producer is altogether le the furnace, the gas which you have produced never gives more about 70 per cent. of the total heat possible by the combustion of iel. In other words, if you take a gas producer, such as the Wilson Dowson, or any other well-known producer of the kind, you will hat you never get in the gas from the producer the full amount of ; if the gas from the producer be burnt it will only give about 70 ent. of the heat that the coal which made the gas would have given nally. There is a loss of 30 per cent. in the producer. The only o avoid this is to have the whole of the producer within the boiler, o prevent producer-loss; but that, in previous attempts, has always found impossible. According to every test made by reliable le up to now, by using a gas producer not more than 70 per at the most, of the original heat of the coal would be sent into oiler, and of that 70 per cent., as in one of the tests here, only 72 ent. would probably be utilised. Therefore I consider that, except unusual circumstances, gas producers could not well be used s with some exceedingly cheap fuel that cannot be burnt in any way. For a fuel that cannot be burnt in an ordinary grate, or in modification of an ordinary grate, it might pay to put down a pro- , but not otherwise.

ith regard to boilers of the water-tube type, I quite agree with Mr. ieyer that they are not satisfactory to the ordinary manufacturer. e had a good deal of experience with them, and it has been my tunate duty to turn them out and replace them with Lancashire s. A good water-tube boiler, such as the Babcock & Wilcox, has great advantage compared with the Lancashire boiler, where you re to get a boiler into a space difficult of access, and also where equire to get a high steam-pressure; but you must carefully con- the difference between the efficiency of the boiler and the effi- y of the engine, and in some cases you will find it would pay to be content with lower pressures and a better and more omical boiler. The main loss, which causes the results obtained with abcock & Wilcox boiler to differ from those with the Lancashire

Mr. Clerk. boiler, is due to radiation and conduction from the fire-brick furnace. Wherever a fire-brick furnace encloses a flame, and the side of the furnace is incandescent, although on touching the outside of the brickwork there would appear to be no serious loss of heat, measurements will show that the heat loss is very great. Reference to many of Longridge's experiments upon boilers of the Babcock & Wilcox type will show that a very great loss of heat is caused in that way, somewhat larger than in the table given by Mr. Crompton. This table in one case gives a loss of 12·7 per cent. heat radiated, but in the Glasgow boiler only 3·22 per cent. That is absurd. There is no boiler ever built that gave such a low loss by radiation.

Mr. Crompton. (Mr. CROMPTON: It is one of Mr. Longridge's tests, made very carefully.)

Mr. Clerk. Mr. CLERK: There is something utterly wrong with it. It is quite obvious that if a furnace be placed in the middle of the boiler, as in the Lancashire boiler, there will be no radiation loss from the furnace, but only the ordinary radiation loss which occurs in every boiler, due to the boiler surface itself. The combustion may not be quite complete, but it is rather a peculiar fact that in Lancashire boilers the highest economy is obtained when the combustion is incomplete. The reason is this: to ensure very complete combustion there must be a large excess of air, and, in consequence, more heat must be carried away.

The types of water-tube boiler, such as the Yarrow, the Thornycroft, and the boilers used by Parsons in the "Turbinia," where the furnace is within the tubes, not without, give all the efficiency with all the advantages of the higher pressure.

Mr. Miller. Mr. H. W. MILLER: Mr. Crompton mentions in his paper the use of special smoke-consuming fire-bridges in boilers for the purpose of improving the combustion. I have been experimenting on that subject for the last three years, more especially for the purpose of reducing the smoke produced by boilers of the Babcock & Wilcox type, and I have achieved a certain amount of success. So much so, that most of the qualities of Welsh coal that come to London, which are only so-called smokeless, can be burned with ease in the Babcock boiler. But, of course, it is quite impossible with the ordinary standard construction to burn the best qualities of Welsh coal such as we ought to use—Ocean, Hills-Plymouth and Nixon's. At present, on account of the production of smoke, we are practically bound to burn coals which are almost semi-anthracitic, and we do not get the good results we should. It is well known that in the ordinary standard pattern of the Babcock & Wilcox boiler there is no real combustion chamber at all; the gases rise from the furnace and immediately go among the tubes and the temperature drops, so that by the time the gases arrive in the so-called combustion chambers at the top of the tubes, the temperature is so low that there is very little combustion at all. The object of putting this special fire-brick, smoke-consuming bridge is to raise the temperature of that point, and so complete the combustion. I find by using the pyrometer, in an ordinary boiler the temperature of flue gases at the top of the tubes, after they have risen from the furnace and gone through the first line of tubes, is from 800° to 1,000° Fahrenheit,

which is much too low to complete combustion. But after fixing the fire-bridge, which consists of a very large mass of fire-brick and hollow spaces through which hot air is introduced, the temperature measure at the back of the bridge is from 1,200 to 1,600 degrees. When you look inside the boiler at this point, instead of it being practically dark, you see the whole space full of flame. The result is that a large proportion of the smoke is consumed. Mr. Crompton also mentioned, and has shown on the screen, some improvements in the type of the Babcock boiler where the chain-grate stoker is used, and he showed the improved form of fire-brick arch. In some boilers which are being built for my Company for use next year I have "gone one better" than Mr. Crompton's design, and have provided a real combustion chamber, so that I hope to be able to burn North Country or Midland coal. In addition to the fire-brick arch which Mr. Crompton showed on the screen, the whole of the tubes of the boiler have been lifted up an extra two feet, a second arch has been put in coming from the back part of the furnace, and a large combustion chamber is formed in that space, entirely lined throughout with fire-brick, and into that space is admitted a certain amount of hot air. By that means I hope to be able to improve the combustion so much that I shall not be obliged to use Welsh coal only in future. Mr. Miller.

Mr. B. BLOUNT: I did not intend to speak at all, but there have been sundry chemical questions raised on which I may be able to say a word, notably in the case of the determination of the efficiency of a boiler, or rather the efficiency of the burning of the fuel for the boiler by the analysis of the gases which come away from the furnace. Various remarkable figures have been stated from time to time as to the percentage of carbonic acid in these gases, and we hear of the percentage running up to a point where it rivals that of the oxygen which has been consumed, which, considering that there is a certain amount of hydrogen in fuel, is absurd. When we pass from those regions of myth and come down to actual facts, we discover that some users of special forms of boiler-grate and the like get really remarkable results—12 per cent. of CO_2 and so on. Personally I have analysed a great number of gases of this kind, but do not find anything of the sort; I find a maximum of something like 10 or 11 per cent., but not more. Then there is another question of the same kind which arises from the analysis of these gases. It is usually supposed—I do not think by the authors of these papers or by those who are likely to speak in this discussion, or by those who have made a special study of the question—but it is supposed by a great number of steam users that they run two serious risks. The one is the loss of energy from the fuel by imperfect combustion, due to the production of some incompletely-oxidised carbon in the form of carbon monoxide. They may relieve their minds as to that. It must be a very badly-run furnace which produces carbon monoxide. Carbon monoxide is rarely found in ordinary flue gases, and if found, the quantity is very small. The second fear, which I can also dispel, arises when they see a little smoke going out of the chimneys; they are afraid they may be ruined. It is much more likely that the neighbourhood will be ruined than that their *pockets will suffer*. Mr. Blount.

Mr. Blount. Mr. Dugald Clerk has spoken a great deal about the disadvantages which he ascribes to the use of a producer. I would like to point out that when a producer is run as it should be with a proper supply of steam, so that the sensible heat of combustion of the fuel used is applied to the production in proper proportion of hydrogen and carbon monoxide, nothing like 30 per cent. of the calorific value of the fuel is lost. And further than that, if the producer is put close up against the object to be heated, the amount of sensible heat which would otherwise be lost can be used and absorbed by the surfaces to which it is applied, just as freely as is the sensible heat of the furnace gases of solid fuel burning in an ordinary grate. Further, there is this point which Mr. Dugald Clerk did not mention—that no one in his senses would think of using a producer for supplying producer-gas to feed a boiler; he would use it for driving a gas engine, and that is a totally different thing. The economy of fuel that can be got in that way is very considerably greater than can be got from the steam engine, putting aside the recovery of the ammonia which has also been spoken of this evening. That recovery of ammonia, I, speaking again as a chemist, a little demur to. I am rather afraid of the market being flooded with that useful material, sulphate of ammonia, which may presently cause it to be sold at something less than the price of the sulphuric acid which it contains. Then, although agriculturists will prosper, the fuel seller and the power raiser will suffer.

Mr. Addenbrooke. Mr. G. L. Addenbrooke: These two papers are difficult to discuss because it is hard to know what is admissible in the discussion. As electrical engineers we are, of course, interested in the cost of raising steam, but we are still more interested in the relative cost of raising steam in comparatively small plants as compared with large plants where every facility can be provided. The problem on which we are at present engaged is to see how far we can replace the steam engines and boilers of factories by steam generated in central stations. Mr. Holliday's paper is exceedingly valuable, not because it goes into the future, but because it gives us figures as to good commercial practice. These figures may be taken as absolutely correct for a large factory, and the question is how far we can do better with them with higher pressures and modern appliances, and, on the other hand, how far it would be possible to supply electric power instead of locally generated power for such plants as Mr. Holliday speaks of. I may say that three or four years ago, in going into this question very carefully, I was exceedingly anxious to get figures of the kind given here; but, after making many inquiries among manufacturers in all directions, I was astonished to find the difficulty there is in getting any really reliable figures. I may, however, quote one or two. The annexed table, which I compiled at the time, gives the cost of running a 50 horse-power and a 100 horse-power steam engine:—

SOUTH STAFFORDSHIRE DISTRICT.

Mr. Addenbrooke.

COST OF INSTALLING AND WORKING STEAM PLANT.

1. *Capital Cost.*

	For 50 I.H.P. £ s. d.		For 100 I.H.P. £ s. d.
Boilers (50 H.P., two; 100 H.P., three)	400 0 0	...	600 0 0
Engine, including cost of belt and gearing for connecting to work ...	250 0 0	...	400 0 0
Pumps, pipes, valves, etc.	100 0 0	...	150 0 0
Boiler- and engine-house, stack, and water arrangements and general expenses of installation	250 0 0	...	300 0 0
Total	£1,000 0 0	...	£1,450 0 0
Cost per Indicated H.P.	20 0 0	...	14 0 0

2. *Annual Cost.*

	For 50 H.P.		For 100 H.P.
Driver and stoker at 40/- per week for 50 H.P.	104 0 0		
Driver and stoker at 45/- per week for 100 H.P.	...	...	117 0 0
Coal, say 5 lbs. per I.H.P. for 2,700 hours per annum, at 5/- per ton, plus 10 % for raising and banking fires ...	82 11 0	...	150 0 0
Oil, waste, etc.	20 0 0	...	30 0 0
Boiler insurance and other expenses ...	6 0 0	...	12 0 0
Interest, say 7½ % on above, depreciation and insurance also 7½ % on above (nothing is specially allowed for rates, taxes, and superintendence, which are considered to be covered in this item)	150 0 0	...	217 0 0
Total annual cost	£362 11 0		£526 10 0
Cost per annum if engine is worked at average of two-thirds of full load, per I.H.P. (which is about what is practically the case)	£10 13 8		£8 4 3
If B.H.P. is taken as the standard instead of I.H.P., the above costs must be increased by 15 %, or to	£12 5 7	...	£9 8 10

The general results of this table show that if you take an ordinary

Mr. Addenbrooke.

engine working under commercial conditions, and the price of coal at about six shillings a ton, the cost comes out at about one penny per indicated H.P. of the engine per hour. By this I do not mean per I.H.P. of the work done, but rather that, supposing you have an engine which is capable of indicating 40 or 50 H.P., the cost will be something like three shillings an hour to run that. These figures are very much higher than those usually given, but I read a paper in the Midlands on the subject of power generation some time ago, and one of the ablest men in the district was very much interested, and took the trouble afterwards to go through the calculations relating to the engine which was driving his works, and which was using coal at about the price named. He had no means of indicating exactly how much the engine was doing, but it was one which indicated 40 H.P. with comparative ease. He found that this engine, including depreciation, interest, superintendence, and every other charge, cost nearly one penny per I.H.P. per hour. It is very important that we should get as many figures as we can of that sort, because they indicate the nature of the margin we have got to work against.

I entirely agree with Mr. Crompton with regard to this question of cheap fuel. I was in the middle of the district where cheap fuel was being used, and, as a matter of fact, I am trustee of a colliery where some of it is raised, and I know perfectly well that as soon as the demand rose, the prices also rose. Mr. Crompton mentions that such fuel depreciates greatly if exposed to the atmosphere. That is perfectly true; and it is also a fact that if the fuel is left in large heaps exposed to the weather, it will absorb very large quantities of water, so that the proportion of water is much higher than it would be under ordinary circumstances. There is another cause of deterioration in collieries where seams are thin and where electric coal-cutting is used, for here they try and cut into the measures below the coal rather than into the coal itself; that is to say, the lower three inches under the coal are cut out by the coal-cutter, and, of course, the dust produced cannot but be mixed largely with the dust and small coal. Therefore I think manufacturers in general feel that there is not very much gain in using these small coals; and it would be a great pity to base any large schemes on the use of coal at less than about 6s. a ton, or probably 7s. a ton as prices go at present.

I was greatly interested in the remarks made by Mr. Blount on the Mond process, to which I have given much attention. As a matter of fact, Mr. Blount says that people should not use the Mond process for raising steam; but, if I am not mistaken, that is the very point which Dr. Mond is working on at present. He is using it for raising steam, and the figures which were given in Mr. Humphrey's paper were undoubtedly very favourable as to the prospects of using the method for this purpose. There is no doubt that we cannot generally rely on recovering the amount of ammonia quoted in Mr. Humphrey's paper at the Institution of Civil Engineers, but I think that the whole method is very well worthy of consideration, quite apart from the question of recovery. There is no doubt that the advantages are very great.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members.

Frank Holden.
Professor Magnus Maclean, D.Sc.

Associate Members.

John Norman Andrews.
Mervyn George Drake.
William Winson Haldane Gee.
Wilfrid Meryon Harris.
Alfred Charles Holtby.
William Owen Horsnaill.
William Cranswick Laidler.
William Bramley Redgrave.
David Evan Roberts.
Sidney John Ross.
Henry Turner.
Arthur James Walker.

Associates.

Cornelius Miles Bradley.
Albert Edward Brown.
George Henry Corringham.
Reginald T. I. Crampton.
James Edward Cuthbertson.
W. C. Dixon.
George E. Etlinger.
Evan Evans.
Robert Foulds.
Daniel Gray.
James Hunter Gray.
Frederick Thomas Hall.
William Archbold Hartly.
Charles Alexander Henderson.
Reginald Archibald Anderson Hooper.
Walter Jenkins.
Duncan McDougall.
David Eardley McLaren.
Frederick Stanley Ransome.
Arthur James Walter.

Students.

John Bentley.
Ernest Brown.
Henry Herbert Crockford.
Frederick A. Frazer.
Harold Griffiths.
Thomas Frederick Griggs.
E. W. Harris.
Arthur Stephens Herbert.
Edward Hutchinson.
William Hunton.
C. Lakin-Smith.
William Upsall Lonnon.
Bernard de Mounteney Mertens.
Thomas Normoyle.
Francis Ernest Pring.
Percival James Robinson.
Henry Mitchell Upton.
John Walker-Hanna.
Theodore H. Watermeyer.
Henry Erskine Newton Wood.

The Three Hundred and Thirty-Seventh Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday, December 7th, 1899—Professor SILVANUS P. THOMPSON, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on November 23rd, 1899, were read and approved.

The names of new candidates for election into the Institution were announced and ordered to be suspended.

The following transfer was announced as having been approved by the Council :—

Richard Lund.

Mr. W. P. Whitehead and Mr. C. S. Thomson were appointed scrutineers for the ballot.

Donations to the Library were announced as having been received from Mr. J. McDonnell and Mr. P. Dawson, Member.

The PRESIDENT : It is suggested to me that I should mention that a meeting is to be held on Wednesday night next, in the Durham College of Science, in Newcastle-on-Tyne, for the purpose of organising a Local Section of this Institution for the north-eastern counties, practically for the counties of Northumberland and Durham. The membership in that part has organised the meeting, at which, in accordance with our Articles of Association, a petition will be prepared to be signed by those who wish to constitute the new branch. The petition will then be presented to the Council of the Institution which will, if it approve, proceed to acknowledge the existence of that local centre. I have been asked by the Council to go down to Newcastle on the occasion. The Secretary will also attend officially, and we shall be glad to see at the meeting any member of any class of this Institution who may be able to be present. It is most desirable that it should be as widely known as possible through the Institution that this local centre is being *organised in* the north-eastern counties.

We will now resume the discussion on the papers by Mr. Holliday and Mr. Crompton, but I will first call upon Mr. Crompton, who wishes to add something to the paper he gave us last week.

Mr. R. E. Crompton: In my paper, I gave a table showing actual results of using cheap fuel under water-tube boilers. Column 2 shows the result actually obtained on a test which was carefully carried out at Glasgow by the well-known Engine, Boiler, and Employers' Liability Insurance Company, and which showed results that would have been good if there had not been passing through the fire a great excess of air which so diluted the products of combustion that 25 per cent. of the units in the calorific value of the fuel went up the chimney. I showed that if this could be prevented by some such means as I described in my paper, the heavy loss (of 25 per cent.) might be reduced possibly to 12 per cent. Since that time, by my wishes, although I was not able to be present myself, a very careful trial has been carried out at Glasgow with the Babcock & Wilcox revolving grate described by me, using the same class of coal, although not quite identical with that referred to in the second column—I should say the coal was rather worse, having a calorific value of only 10,900 to 11,000 units—and that result, obtained by this test, corroborates my figures in the third column as regards the heat carried off in the products of combustion and in the excess of air. I have had the results very carefully prepared, and distributed to-night in the form of an addendum to my paper. These figures show that practically there were about 12½ per cent. only of the heat units carried off in the waste gases, and this, I think, justifies the figures in my third column, where I gave 12 per cent. But it will be seen that I was too sanguine in supposing that I should be able to reduce the losses three and four in my table which in my fifth column I have got as low as about 600 units. In this last Glasgow trial these losses came to 1,400 units, or 12 per cent., instead of the 5 per cent. I calculated on. Although this is so, I do not at all despair of getting to my figures, because a great many of the losses unaccounted for are due to the units used in evaporating the large quantity of water contained in the fuel in this trial; and further than that, the boiler was set in such a manner that the radiation losses were considerable. Mr. Crompton.

Just after the date of reading my paper I received a communication from Mr. Dickinson, the engineer of the Leeds station, who has been singularly successful in utilising extremely cheap fuel by a well contrived furnace. I will read the communication, as I think it may well form part of the discussion. "The Leeds lighting station started in May, 1893, and from then to the end of that year the fuel used was slack, costing 7s. per ton. It was then found that much more economical results were obtained by the use of smudge (a local name for the fine dust) costing only 2s. 3d. per ton delivered, and this class of fuel has been used exclusively till the beginning of this year. During that period, however, the price of smudge has been gradually rising, owing to an increased demand for it

[illegible] after six months' [illegible] would be still [illegible]

[illegible] congratulated on [illegible] engineers are people [illegible] them questions of [illegible] any other class of [illegible] rather to be read before [illegible] Institution of Electrical Engineers than before any other engineering society. In this country we have few waterfalls and cheap coal, contrasting very much with what we saw in our summer trip to

Switzerland, and we welcome any papers like these which give us actual figures. Professor Perry.

I think I agree with pretty well all the remarks that Mr. Crompton has made in his paper on furnaces in general, and I hope that his own furnace has a great future before it. Our old theoretical notions are coming to the front. I need not refer to the notions about high speed, high pressure, super-heating, and steam-jacketting. Theoretical notions as first published are usually incomplete, and it is not until there are attempts to carry them out by good practical engineers who have commonsense that everybody gets to see what a lot of force there is in these thermo-dynamic notions.

Boilers in general have been spoken of during the reading of the paper. Well, many of us have said that it is very important to have a good combustion chamber, and that if we cannot get complete combustion otherwise, then we ought to have a combustion chamber completely lined with fire-brick. I notice that in one of Mr. Thornycroft's latest patents he proposes to use a fire-brick lined combustion chamber with his water-tube boilers. I should like to point out that heating surface by itself is really not a very important thing in boilers. More important than this is the smallness of what the hydraulic engineer calls the hydraulic mean depth of the flues; it is enormously important if heat is to be given from gases to metal, that the metal should be scrubbed with the gases. The velocity of the gases in the flue is the most important thing. From experiments that have been very carefully carried out, it is quite clear that when the average velocity in the flue is doubled, twice as much heat is given to the metal, and when the velocity is trebled, three times the heat is imparted to it. But on the other side of the metal the water has to take up the heat from the flue. Very little attention is really paid to this question. In the old days of low pressures, steam had small density: a pound of evaporation meant a great volume. The result was that there was a great commotion of the water, and a great deal of circulation, which may be termed natural circulation. In these days of high pressures the steam is very dense and there is nothing like the same commotion of water per pound of evaporation, and I think we are all coming round to the idea that we must have mechanical stirring of the water of a boiler. Much of the increase of economy in recent boilers that is ascribed to other things is really due to the fact that those other things produce more commotion of the water and a better scrubbing of the metal surface.

There is another point to which sufficient attention is not paid, and that is the fact that in modern boilers for condensing engines the water in the boiler is airless water. A great chemist told me some little time ago that airless water cannot be boiled. Doubtless there is great difficulty in heating airless water, and still more difficulty in boiling it. But it can be boiled, and we know that it is boiled regularly. This is the reason why there is so much trouble sometimes with ordinary cylindrical marine boilers, and I think one of the great merits of Thornycroft was in his seeing that not only must there be a rapid circulation and *scrubbing action of the* water on the metal, but a

Professor Perry.

gurgling scrubbing action, such as we have in his water-tube boilers. However, I have published elsewhere my notions about boilers in general, and I should like to speak of some of the figures of the papers.

Mr. Holliday has compared in his paper the costs of evaporating with two kinds of fuel, bought at 3s. 6d. and 14s. 6d. per ton respectively, giving both the cost of the coal alone and the total cost of evaporating 1,000 gallons of water. Mr. Crompton has seen that it is very important to consider the load factor, and he has taken two common load factors, and has based his calculations on these. Mr. Holliday has employed a very high load factor, and I have endeavoured to utilise the figures he has given us in making calculations concerning many other load factors than his. The method of calculation that I have adopted is communicated as an addendum to my remarks in the discussion. I should like to make a comparison between the numbers I have worked out and those published by Mr. Crompton, but unfortunately his costs are not the total costs that Mr. Holliday is speaking of. He takes the cost of coal and the working expenses, but I have accepted Mr. Holliday's conditions and have included the cost of maintenance and insurance, rates and taxes, and rent, and have taken the price of coal under Mr. Holliday's conditions. There is only one point on which I can make a comparison with Mr. Crompton, and I am sorry to say that here my figures do not quite agree with his, and I was tempted not to take part in this discussion on account of my difference from such a practical authority as Mr. Crompton. I might as well point out what the difference is. You will see in the table on the last page of Mr. Crompton's paper certain figures which will enable you at once to calculate for the four cases the number of pounds of coal per unit used by him. With the 17s. 5d. coal, the dear coal, with 18 per cent. load factor—I take one of his load factors as 18 per cent. and the other 33 per cent.—I find he takes 5·23 lbs. of coal per unit in the first case and 5·24 lbs. in the second case; and for the cheap coal, the 5s. 4d. coal, it is 5·14 lbs. of coal in the first case and 5·17 in the second. My formula gives 6·57 in the first case and 4·48 in the second, with 10 and 6·85 respectively for the cheap coal. I think Mr. Crompton's numbers are too nearly equal, but one must not criticise figures obtained in actual practice at Chelmsford. I think, however, that my figures probably represent the more usual results obtained at a good central station. Mr. Crompton has promised to check my figures, and we will go into the thing, and possibly I may be allowed to correct these figures after Mr. Crompton has gone over them. [It is easy to see why, assuming Mr. Crompton's station to work 24 hours a day, I found his load factors to be 18 and 33 per cent. In truth, it was a workshop-power-station, working in every case upon a load factor of more than 60 per cent., and hence there is no obvious disagreement between our figures.]

In the annexed table are given the results which I have obtained by taking the data given in Mr. Holliday's paper. The prices of coal here are given under Mr. Holliday's conditions. For the load factor of 10 per cent., we see that the cost per electric unit with the cheap coal is 2·5d., and with the more expensive coals it was 2·45, 2·40, *2·33, 2·27, and* 2·24. That is, we have the cost of the unit, so far as

Professor Perry.

TOTAL COST OF EVAPORATION PER ELECTRICAL UNIT DELIVERED BY AN ORDINARY CENTRAL STATION. ALSO THE EVAPORATION AND WEIGHT OF COAL AND COST IN PENCE OF COAL ONLY PER ELECTRIC UNIT DELIVERED.

Load Factor. Per cent.	lb. Evaporation.	Coal at these Various Prices per Ton.																	
		3s. 6d.			5s. 4d.			7s. 6d.			10s. 6d.			14s. 6d.			17s. 5d.		
		lb. Coal.	Coal Cost.	Total Cost.	lb. Coal.	Coal Cost.	Total Cost.	lb. Coal.	Coal Cost.	Total Cost.	lb. Coal.	Coal Cost.	Total Cost.	lb. Coal.	Coal Cost.	Total Cost.	lb. Coal.	Coal Cost.	Total Cost.
5	201	31·1	·55	8·35	28·6	·78	7·94	26·1	1·00	7·53	23·3	1·25	7·29	20·4	1·50	6·60	18·6	1·65	6·32
7½	141	21·8	·39	4·08	20·0	·55	3·94	18·3	·70	3·79	16·3	·88	3·64	14·3	1·06	3·47	13·8	1·16	3·38
10	111	17·2	·31	2·51	15·8	·43	2·45	14·4	·55	2·40	12·8	·69	2·33	11·2	·83	2·27	10·3	·92	2·24
20	66	10·2	·20	0·87	9·4	·26	·88	8·56	·33	·90	7·64	·41	·92	6·68	·50	·94	6·12	·54	·95
40	43·5	6·7	·12	·36	6·2	·16	·39	5·65	·22	·42	5·04	·27	·45	4·41	·33	·49	4·03	·36	·50
70	34	5·3	·09	·21	4·8	·13	·24	4·48	·17	·27	3·94	·21	·30	3·44	·25	·33	3·15	·28	·35

Note.—I have obtained these results by calculating with Mr. Holliday's numbers. I may say that the same general lesson is taught, whatever reasonable rules are taken, for either good or bad central stations near to or far from coal pits. This is the general rule: For stations with high load factors it is better to use *cheap* coal; for stations with small load factors it is better to use expensive coal: there is a certain load factor for which cheap and dear coals are equally good to use. It seems to be about 15 per cent. in all cases.

Professor Perry.

evaporation is concerned (this is only the cost of evaporation), diminishing as the price of the coal increases. Again taking the load factor of 15 per cent., common in many electric lighting stations, we find that it seems to make very little difference indeed whether you use cheap coal or a very expensive coal[1]; whereas if you have a higher load factor, say 20 or 40 per cent., it is more costly to use more expensive coal. Still more is it so when you have as high a load factor as 70 per cent.

[*Communicated*] METHOD OF CALCULATION.—If we plot from Mr. Holliday's forced draught trials, E the average evaporation in pounds per hour each month, and C the coal in pounds per hour, we find that the points lie very exactly in a straight line and satisfy the rule

$$E = 6{\cdot}3\ C - 207.$$

There is much less consistency in the natural draught results. But in the spare boiler trials there is a wonderful consistency, although their load factors were small compared with the others; for these we may take as very true the rule

$$E = 6\ C.$$

I cannot understand how these spare boilers can be so uneconomical with coal costing nearly three times the forced draught coal. I shall use only his forced and natural draught results. I find that 1 lb. of his steam represents 1·055 standard units of evaporation. His forced and natural draught trials were all at high load factors. If I am to use his results for various load factors, large and small, considering the usual results obtained in electric light central stations, I think it safe to say that the following rule is fairly consistent with Mr. Holliday's results and our general knowledge: if E is evaporation in pounds (standard, that is at and from 212° F.) per hour, and C means pounds of coal per hour, the coal costing c shillings per ton at Mr. Holliday's place,

$$E = (5{\cdot}38 + 0{\cdot}31\ c)\ C \ldots\ldots \qquad (1)$$

I need hardly say that this formula, deduced from Mr. Holliday's use of 3s. 6d. and 14s. 6d. coal, must not be applied much outside his limits, and indeed it must not be put to a more exact use than the following rough generalisation.

In a small electric light installation, and especially if there are only two boiler shifts of men, the following rule as to cost must be wrong. Nor can any rule be easily given for such a case. If we carefully consider the conditions of a well-arranged central station with three eight-hour shifts of men seven days a week, as the station is larger and larger it is more and more nearly true that such part of the working expenses as alter with the load ought to be proportional to the load. Common sense tells us that we ought to have some such law as—

$$\text{Cost per month} = a + (\alpha + \beta c)\ C^1,$$

if C^1 tons of coal are burnt per month, c being the cost of a ton of coal and a being proportional to the first cost of the boiler plant, α and β being constants. This seems to be borne out by the forced draught trials, for if working cost per month and coals be plotted we find points lying very well in a straight line. In the natural draught trials there is *no simple law*, and this is accounted for by the fact that the working

cost is not great in comparison with the other costs. On the whole, however, it will be found that all the results of forced and natural draught trials agree very closely with the rule, Professor Perry.

$$\left.\begin{array}{r}\text{Total cost in shillings of evapora-}\\ \text{tion per ton of coals used} \ \ldots\end{array}\right\} = c + 1{\cdot}06 + \frac{2{\cdot}4}{f} \ldots . \quad (2)$$

where f is the load factor. In any reasoning upon this subject the form of (2) is important because it indicates that much of the cost of boiler plant is proportional, not to the greatest evaporation expected, but rather to the greatest amount of coal we expect to burn.

This idea is clearly indicated in the figures of Mr. Holliday's Table V. Consider two plants with the same load factor, say 60 per cent., both capable of evaporating a maximum amount of 1,667 gallons in any particular time; we shall find if we divide up the costs of Table V. that we have

Cost of Coal per Ton.	Costs in Pence.		
	Coal used.	Working expenses.	Maintenance, interest, and depreciation, rent, taxes, rates.
14s. 5¼d.	80·5	11·9	13·4
4s. 3½d.	37·8	20·7	17·5

If the numbers in the fourth column had been equal, it would have indicated that the cost of the boiler plant was proportional to the maximum evaporation expected; whereas we see that they are in the way of being proportional to the maximum amount of coal expected to be burnt.

I dwell upon this matter because it is not difficult to show that if a substantial part of the fixed expense which is independent of load factor is proportional to the maximum weight of coal which may be burnt, then with almost any conditions of price per ton and evaporative power such as I state in (1), my conclusion is a very general and rather important conclusion. It follows from (1) and (2) that to evaporate 1,000 gallons of water from and at 212° F. costs in shillings

$$\frac{{\cdot}83\left(1{\cdot}06 + c + \frac{2{\cdot}4}{f}\right)}{1 + {\cdot}058\,c} \ldots\ldots\ldots \quad (3)$$

Also it is evident that

$$\frac{\text{Cost of coal}}{\text{Total cost of evaporation}} = \frac{c}{1{\cdot}06 + c + \frac{2{\cdot}4}{f}} \ldots . \quad (4)$$

The following numbers do not show a particularly good economy in the engines and dynamos and distribution system of an electric supply company, *but it is well known that they* are not unusual :—

ofessor rry.

Load factor.	Evaporation in standard units per electrical unit sold.
·18	71
1·00	30

We may then take for any other load factor f,

$$\left.\begin{array}{r}\text{Pounds of evaporation per}\\ \text{unit of energy sold}\ \ldots\end{array}\right\} = 21 + \frac{9}{f} \quad \ldots\ldots \qquad (5)$$

$$\left.\begin{array}{r}\text{and pounds of coal per unit}\\ \text{of energy sold}\ \ \ldots\end{array}\right\} = 3{\cdot}9\ \frac{1 + \dfrac{3}{7f}}{1 + 0{\cdot}058\,c} \quad \ldots\ldots \qquad (6)$$

and hence from (3)—

$$\left.\begin{array}{l}\text{Total cost of evapora-}\\ \quad\text{tion in pence per}\\ \quad\text{unit of electrical}\\ \quad\text{energy sold}\ \ \ldots\end{array}\right\} = K = \frac{1}{50}\ \frac{\left(1{\cdot}06 + c + \dfrac{2{\cdot}4}{f}\right)\left(1 + \dfrac{3}{7f}\right)}{1 + 0{\cdot}058\,c} \quad \ldots \qquad (7)$$

The table given above has been calculated from this.

It is easy to see that whatever be the law connecting evaporation and electrical units, for any given value of the power factor

$$K \propto \frac{1{\cdot}06 + \dfrac{2{\cdot}4}{f} + c}{17{\cdot}4 + c}$$

Hence if $1{\cdot}06 + \dfrac{2{\cdot}4}{f} = 17{\cdot}4$ or $f = {\cdot}146$, then K is independent of the cost of coal per ton.

If $1{\cdot}06 + \dfrac{2{\cdot}4}{f} > 17{\cdot}4$ or f less than ·146, then K gets less as more expensive coal is used.

If $1{\cdot}06 + \dfrac{2{\cdot}4}{f} < 17{\cdot}4$ or f is greater than ·146, then K gets greater as more expensive coal is used.

olbred. Mr. J. N. SHOOLBRED: We must all be very thankful to Mr. Holliday for the array of facts which he has brought before us, but the circumstances under which the conditions have been arrived at should be noted. He has a large stack of boilers running the whole week, and, practically, with a mill-load, differing very considerably from the load which we at present have in electric light stations. The result is that he is working under almost ideal conditions, such as we cannot yet hope to arrive at.

I think it will generally be found that forced draught in circumstances which are of a much more intermittent character than those which have been mentioned by Mr. Holliday, is not as successful as the author's results would show. The principle of forced draught, in itself, is hardly answerable for that, because the conditions in which it is used are those entailing intermittent action and very considerable variation in the temperature of the pipes. However, the fact remains that in the majority of circumstances where forced draught is at present introduced for electric lighting stations, the conditions are not so ideal or so beneficial as Mr. Holliday would show.

With regard to the difference of the cost of fuels, Mr. Holliday points out that the cheaper fuels—not the very cheap fuels, but the

cheaper fuels—are actually more economical to use than the high-class coals which are now so widely used; and Mr. Dickinson's interesting figures that have just been read seem to confirm this. Mr. Dickinson speaks of smudge and of slack. The slack in itself which he speaks of at 7s. a ton—and I have experience in the neighbourhood of Leeds of that very class of slack—is really coal; which, though small in itself and comparatively cheap, has a relatively high calorific value. He refers to the smudge, where it descends into a very inferior quality of coal, as not giving the same satisfactory results. My own experience of a good many years, and with different qualities of coal, quite coincides with that statement; and I believe that it is possible to push economy too far. By resting contented with a coal giving really fair calorific results, we have made considerable economy. The reason why these low-priced coals are really more economical is that, at the present time, the calorific value of these coals does not decrease in the same proportion as does their market value. Mr. Shoolbr

Excluding London and other districts remote from the coal-bearing strata, that coal the rate for which is about the middle of the range of market prices produces a calorific value which probably is 75 per cent. of that of the best coal, and the results obtained in using such a coal are, naturally, economical. With regard to the cheaper qualities of "smudge," and the more inferior fuel, breeze, which Mr. Holliday refers to, it is due largely to the great proportion of incombustible matter, and to the very variable quality of this calorific value, that these cheap fuels, especially if assisted with forced draught, do not give the satisfactory results that are obtained with the middle-class coal. I may have been unfortunate in the results which I have personally had with "breeze"; but I find that many others are of a similar opinion. Namely, that the economy, supposed to result from the use of these cheap fuels, and particularly with breeze, is not in favour of the steam-raiser; but rather of the gas people who wish to palm off an almost worthless article. To get rid of it they are willing to sacrifice the other department that has the unfortunate duty of raising steam for them.

With regard to the question of mechanical stokers, it appears to me that you can descend too low in the scale and use too cheap a fuel; so cheap that, though you can use it with hand-firing, you are bound, in some cases, to take a better and more expensive coal for stokers that are supposed to be able to burn anything.

Mr. H. L. P. Boot: We are all indebted to the authors for bringing this important matter before us, and I have long regretted the fact that we, as engineers, do not make public the actual results obtained by the use of different fuels. Fortunately, I have been allowed to experiment with a number of different classes of fuel, but owing to the geographical position of the town in which the experiments were carried out they relate principally to Welsh fuel. The following figures, obtained with Welsh coal, represent the cost of the fuel only per unit of electricity generated:— Mr. Boot

Nixon's Navigation	1·02d. per unit.
Ocean Co.'s Wash Nuts and Large ...	·96d. ,,

Mr. Bost.

Hood's Merthyr Nuts	·79d. per unit.	
Waynes " "	1·2d.	"
Gelli, Wash Nuts	·96d.	"
Coke at 15s. a ton (which is the price paid there)	·879d.	"
Tydraw	·894d.	"
Great Western Colliery Co.'s coal ...	·810d.	"

These results were obtained under actual working conditions with an 8 per cent. factor, the average price of a good class of coal in that particular town being something like 24s. to 26s. per ton.

It is interesting to compare also the relative costs of using inferior fuel and a better class of fuel, in the case of a district in which the railway rate is high. If you take into account the freight, which, in many instances is twice as much as the value of the fuel, you will see at once that it is necessary to burn the very best class of fuel possible, so as not to pay too high a proportion to the railway companies. I have taken figures which include railway rate, unloading, stoking, getting rid of ashes, and the capital outlay required for boilers, and find that when using a fuel costing 5s. at the pit's mouth, the total cost being 16s. 9d. per ton, which we should consider a bad class of fuel, and comparing that with the best class of fuel, which would cost with us 24s. per ton (that is to say, allowing for a similar outlay on boilers, owing to the higher evaporation, the fact that you have got to deal with a very small percentage of ash, and that very often one stoker can do the work hitherto requiring two, and also that the cost of unloading is very much less, the railway rate being the same), the total difference working under these conditions amounts to ·184d. per unit. If you take the works cost in the town which I represent, and deduct the difference between the cost of coal per unit from the cost of coal per unit in Leeds, which [illegible] you will find there is as big a difference in the [illegible] ·7½d. from the total works cost [illegible] per unit here.

[illegible] was touched on at the last [illegible] indeed, and that is the [illegible] Owing to the longer [illegible] compares unfavourably with coal [illegible] the same quality when [illegible] I have made tests of one month that [illegible] the same. I also carried [illegible] under the same conditions [illegible] particular coal the loss was [illegible] had it been burned [illegible] that extra calorific [illegible] touched upon is the [illegible] in the cost of [illegible] can speak from [illegible] the last meeting that [illegible] was the fact that, if a [illegible] your fires and probably drop

your pressure. Speaking from considerable experience on this matter, Mr. Boot. having very bad water to deal with, and using tubular boilers, I can say that such a course has not been necessary in a single instance. It is only just to tubular boilers that that fact should be known, that although a tube may burst, (unless it is a very bad one indeed) there is no need whatever to draw your fires before the boiler can be spared. The boiler is quite capable of going on working.

Mr. W. GEIPEL: Not a few electric lighting stations are now face to Mr. Geipel. face with the difficulty of raising more steam than they can well produce with their existing boilers. We all, as central station engineers, know how important a bearing this question of load factor has on the ultimate results as to the coal used per unit of energy supplied to the mains. The load factor of the boilers described by Mr. Holliday is almost constant, a load factor which we have never in our experience been fortunate enough to come across in electric lighting at any rate. It may be that as our stations partake more of the nature of power stations the load factor will be more comparable with what Mr. Holliday has brought before us, but at any rate at present we have got to face a very different state of affairs. Mr. Holliday says, taking this load factor, that he finds the cost of fuel is the predominant cost in the production of steam. Some of the speakers in this discussion have pointed out the importance of other factors besides the question of coal. Professor Perry has a table which, as I understand, shows the important bearing which capital outlay has upon the total cost of producing electrical energy. The number of boilers which have to be put down to produce the steam required has also an important bearing on the question of capital cost, and therefore it cannot be passed over. These boilers that we are now discussing are using forced draught, and have, as I calculate (although it is not given in the paper), about 850 square feet of heating surface on the average for each boiler, and gave only 7·2 lbs. of water evaporated per pound of coal. With forced draught we get three to four times that quantity of coal, and what does that mean? —that a good boiler will cost three to four times less, if properly installed and properly worked, than the boilers which are working at this present rate. Then in the case of hand-worked boilers Mr. Holliday has only an evaporation of 4 to 4½ lbs. per square foot, and it is not surprising that he should make the remark that he finds better results as he gets more work for his boilers to do. We want to force our boilers over the peaks of the load. Mr. Ferranti has hit the nail on the head when he says what we want is plenty of steam so that we can keep some of our boilers as a spare over the heavy load, and so that we can keep them clean. Mr. Boot has very rightly referred to the effect of sediment on the efficiency of the boilers, and it is for this reason that it is so important to have spare boiler power, so that the boilers may be cleaned. Mr. Holliday has not had the difficulty, which we, as electrical engineers, have to face, of raising steam every day, probably for two or three hours, from the majority of boilers. That we know is a very serious difficulty, and it is just there where the Babcock & Wilcox, or other water-tube boilers, come in. *It may be that* the water-tube boiler is less efficient *with some classes of coal if you take* it for a twenty-four

Mr. Geipel. hours load where the question of raising steam is not one of importance. But where you have to produce steam for two or three hours' use, this question of steam-raising is most important.

It has been acknowledged, as is well known, that Lancashire boilers are very costly and wasteful in this respect. Mr. Mountain in his paper (I think it was before the Northern Society some years ago) states that for hours after steam has been raised the boiler is cold at the bottom, showing that the water has not attained to the proper evaporating point throughout the boiler. Professor Perry pointed out the importance in high-pressure working of the water being thoroughly and regularly heated throughout the boiler, and to ensure that he suggested mechanical circulation. I am quite sure that this would have very beneficial results, but there is another and very simple means, which my firm

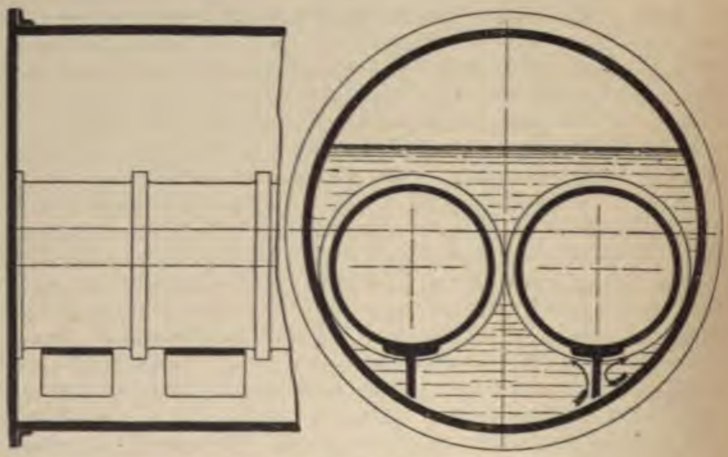

Fig. A.—Boiler with Circulating Rib.

uses, in actual practice, to obtain the same result. By attaching to the bottom of the flue of the Lancashire boiler a thick rib of iron (Fig. A) we induce a circulation by means of the thermal conductivity of the iron. It is well known that water alone will not transmit heat downwards except at a very low rate. But by attaching the iron rib underneath the fire, and underneath the flue, the heat is carried down to the bottom and causes the heating of the water there, thus inducing a circulation in the direction shown by the arrows in the figure. This may appear to be a somewhat theoretical proposal, but the curve in Fig. B shows the actual result of applying this system. The curve is certainly taken from laboratory tests, but I wish you clearly to understand that we have found the tests to be quite borne out in practice. The curve is drawn from a test made without the rib, simply taking the bottom of the boiler and heating the water downwards, and shows the rising temperature at intervals of one minute, or of five minutes. Without the rib the temperature rises at the bottom of the water in twenty-five

Mr. Geipel.

minutes by something like 25° F. Then having exactly the same conditions in every way, except that a rib of iron is put at the bottom of the water, an increase of temperature of 115° F. is found in the same period, which is about four or five times the increase of temperature obtained without the rib. The arrangement is very simply applied, as it is simply a "T" iron riveted on the bottom of the boiler. You can make it as short as you like to facilitate cleansing, but once start the circulation in the bottom of the boiler and it is extraordinary how it draws the water to it.

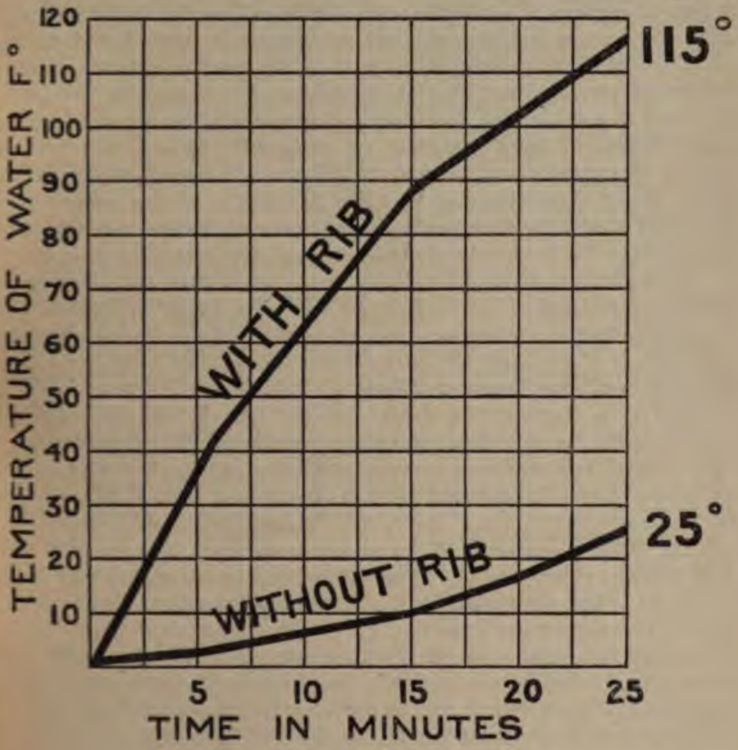

FIG. B.

In speaking of inferior fuels, I may mention that we have recently had experience with the use of inferior fuel as compared with good fuel in the same town, viz., Chatham, where we have two stations running, one being a very small one and using inferior coal with forced draught, the other being a large station using a better coal on account of the smoke difficulty. Here we confirm very much what Mr. Boot has stated; we have 0·75 of the cost per unit with inferior coal against about double that cost with the Welsh coal.

Mr. Crompton has spoken of the difficulty of coking stokers. I agree with Mr. Crompton entirely that coking stokers are not suited for

Mr. Geipel. all coal, owing to the difficulty of keeping the grate properly covered and free from air spaces. But that difficulty I have never seen yet with a properly arranged spreading stoker. With spreading stokers the fire is fairly level throughout, and the clinker, which Mr. Crompton referred to as being a difficulty, is very much reduced as compared with what one has in hand-firing; what clinker there is is passed over the end of the fire-bars, and there is very little trouble indeed with this form of stoking. There are various kinds of spreading stoker; those I have seen mostly in use being Bennis stokers.

I quite agree with Mr. Crompton that it is most important that the proper proportion of heating surface and grate area should be arranged according to the fuel, draught, and other circumstances, but I do not quite agree with the system of putting the coal outside the boiler. Wherever you have heat you are bound to have conduction and radiation, and if you can get your furnace surrounded by water it is very much better. I have lately had an opportunity of seeing how they tackled this question at Frankfort. They had a large tubular boiler much like a Cornish boiler, but the furnace itself was enormously increased in size by a particular arrangement of the boiler which kept the whole of the fire inside of the boiler and surrounded by water.

In conclusion, I would point out an interesting coincidence in Table V. at the end of Mr. Holliday's paper. Depreciation is calculated at 5 per cent. per annum on the cost of the boiler. The amount set aside forms 5 per cent of the total yearly working costs, and that amounts to 5d. per thousand gallons.

Mr. Lawson. Mr. A. J. LAWSON: I think that we are all indebted to Mr. Crompton for the very valuable suggestions he brings before us from time to time. I remember some years ago, when passing through London on my way from the extreme West to the extreme East, Mr. Crompton pointed out to me that coal at one of the London stations, a continuous-current station, was used at the rate of from 6 lbs. to 7 lbs. per unit sold, whereas at some of the other stations in London at that time from 12 lbs. to 13 lbs. were consumed. Subsequent reports and analyses of reports have shown that he was quite right. Some years ago we had from him a paper in which he suggested 3d. per unit as the cost of electricity, and many of us, having then to deal with the older stations, were very much frightened at the figure he quoted. But since that time provisional orders and bills have been passed through Parliament, in which we have as a maximum for the supply of power during the day a price not exceeding 3d. per unit for the first hour and ·825d. for every subsequent hour, or an average for an eight-hour working day of 1d. per unit. Mr. Crompton has done well in bringing before us this question of the influence of cheap fuel upon the cost of production, so that we may see how to be able to produce electricity at that figure and to make it pay.

Respecting his remarks at page 66 of his paper, I can confirm from a long experience his statements as to the difficulties arising from the adhesion of clinker to the brickwork, which is always considerably damaged in the operation of removal of the clinker, and as a rule lasts but a very short time. My experience suggests, with regard

to double-furnace boilers, especially of the Babcock & Wilcox type, that we should never put double arches over the deadplates, but always a single arch, and have between the two doors a dividing wall—not a supporting wall, because such a wall, being fired on both sides, is always rapidly eaten into and broken away by the clinker and heating, and breaks down the arch. The cost of re-lining a single arch furnace is much less than half that of re-lining a double arch. Mr. Lawson

Now as to relative costs. Taking stations in which Welsh coal is burned under boilers, but similar in all respects to other stations in which North Country rough small coal automatically stoked is used, I have found the cost of repairs in the former case to work out at about ·033d. per unit, while the cost in the latter was ·150d., or four and a half times as much as in the former case, taking the average of two stations of each kind for two years. We must also take into account the greater quantity of ash and clinker to be removed, and this quantity will be found to be from two to three times greater in the case of the small bituminous coal than in the case of Welsh coal. As a set-off, however, we have in London and the South generally to pay at least 50 per cent. more for Welsh coal, and also more for handling and storing, as well as more in stokers' wages, while the evaporating value is only 25 per cent. greater than that of the North Country coal which has been mentioned. At the present time on contracts, North Country rough small coal waterborne is obtainable in London alongside at 12s. per ton, whereas the best Welsh, also waterborne, will cost 20s. It will cost undoubtedly more at present, but I assume that contracts have been placed in the early part of the year. If we use South Hetton or Harton rough small, with good automatic stoking, and take into account the economisers, we shall get an ordinary evaporation of 8 lbs. of water, actual, per lb. of coal, while Welsh coal will evaporate 10 lbs., taking the economiser into account. But, however important it may be to use cheap fuel, it is very much more important to use an economical engine. Taking steam consumption from 20 lbs. per I.H.P. downwards, and the over-all efficiency of engine and direct-coupled dynamo or alternator at about 80 per cent., or say 600 watts delivered at the terminals of an alternator for every I.H.P. of the engine, assuming no other losses such as steam required for auxiliary engines and pumps or radiation, then 1⅔ H.P. hours are required to produce a unit of electricity. The accompanying tables show that for an engine taking 18 lbs. of steam per I.H.P. per hour the cost will be ⅕d., or rather ·201d. per unit generated, when using coal at 10s. per ton. With coal at 12s., the engine should, for equal fuel-cost, be such as not to consume more than 15 lbs. per I.H.P. With coal costing 14s. per ton delivered, the engine should not consume quite 13 lbs. per I.H.P. These figures relate to North Country coal. With Welsh coal costing 14s. per ton, evaporating 10 lbs. of water per pound of coal used, to obtain the same results the engine should not consume more than 16 lbs. of steam, as against 18 lbs. of steam for the 10s. North Country coal.

Some speakers have dwelt on the very much greater area required for the burning of North Country coal, and on the much less work to be

Lawson. Cost of Fuel per B.T. Unit Generated, with Coal Evaporating 8 lbs. of Water per Pound of Coal, the Ton of Coal Costing Delivered—

Pounds of Steam per I.H.P. hour.	10/-	12/-	14/-	16/-	18/-
20	·223	·268	·312	·357	·402
19	·212	·255	·296	·339	·382
18	·201	·241	·281	·321	·362
17	·190	·228	·265	·303	·342
16	·178	·214	·250	·286	·322
15	·167	·201	·234	·268	·301
14	·156	·188	·218	·250	·281
13	·145	·174	·203	·232	·261
12	·134	·161	·187	·214	·241
11	·123	·147	·172	·196	·221
10	·112	·134	·156	·179	·201

For Coal costing : 5/-, 6/-, 7/-, 8/-, 9/-, take half of above figures.

Cost of Fuel per B.T. Unit Generated with Coal Evaporating 10 lbs. of Water per Pound of Coal, the Ton Costing Delivered—

Pounds of Steam per I.H.P. hour.	14/-	16/-	18/-	20/-	22/-	24/-
20	·250	·286	·321	·357	·393	·429
19	·237	·272	·305	·339	·373	·408
18	·225	·257	·289	·321	·354	·387
17	·212	·243	·273	·303	·334	·365
16	·200	·229	·257	·286	·314	·343
15	·187	·215	·241	·268	·295	·322
14	·175	·200	·225	·250	·275	·300
13	·162	·186	·209	·232	·255	·279
12	·150	·172	·192	·214	·236	·257
11	·137	·157	·177	·196	·216	·236
10	·125	·143	·161	·178	·196	·215

For Coal costing : 7/-, 8/-, 9/-, 10/-, 11/-, 12/-, take half of above figures.

got out of boilers in consequence of its use. I have not found that to be the case. Taking Babcock & Wilcox boilers rated at about 5,700, or roughly 6,000 lbs. of water per hour, using small coal, we have been able to get on long-continued runs an evaporation of from 7,500 lbs. to 8,000 lbs. In any station where the load has to be run up rapidly it is impossible to find a better boiler than the water-tube boiler, for a full head of steam can with ease be got up from a cold boiler in three-quarters of an hour. To do this safely with the Lancashire type of boiler, at the very least twenty-four hours will be necessary. I do not know what may be done with such boilers as the 'Economic' made by Davy Paxman, but probably a great deal better. I have had some experience of them, but I have not the figures before me at the moment to say what can be done. Mr. Lawson.

Professor R. H. Smith: Professor Perry says that the question of economy is of special importance to electrical engineers as they have to deal with the production of energy; but I think that is hardly a good reason, for every class of engineer, every kind of mechanical engineer at any rate, has also to do with the generation of energy, and in fact every problem in engineering, civil, mechanical, electrical, mining, and every other kind of engineering, is equally concerned with questions of economy. Economy is of as great importance in the one department of engineering as in the other, at least normally. The questions of saving of expense in fuel and in some other directions, have appeared to be of greater importance in electrical engineering than in some other classes of engineering, because there is less margin for profit in the operations of electrical engineering than in many of the others. There are natural disabilities in several departments of electrical engineering that tell against it in competition with other kinds of engineering, and this compels electrical engineers to pay more attention to saving with regard to fuel. Professor Smith.

Mr. Holliday's paper, I think, does not go in the direction Mr. Shoolbred suggests of greatly favouring very cheap fuels, but rather, as it appears to me, the contrary. He makes two or three points on page 42 against cheap coals which I think are important, for instance the enlargement of either the size or the number of the boilers. Given the horse-power, cheap coal is the most important point. Then again, the extra amount of refuse to be got rid of, the expense of that is another very important point which tells against cheap fuels; and the extra storage and space for fuel is again important. I am doubtful as to the truth of what he says with regard to the extra high temperature that is necessary in the chimney gases with cheap fuels. He says forced draught necessitates a higher temperature in the chimney gases. Of course it is a generally known fact that chimney temperature is higher with forced draught than without it, but I have never found any reason for believing that it is a necessity of the case. If forced draught were more intelligently applied, if the arrangements in connection with it were better thought out, we might have a lower temperature at the base of our chimneys than without it. With forced draught, I have sent my flue gases into the base of the chimney considerably cooler than the steam inside the boiler. I do not boast of *that* as a result to be desired,

Professor Smith.

but it shows there is a possibility of getting practically all the heat that can be theoretically obtained from the hot gases before they go into the chimney.

There is another point in Mr. Holliday's paper which is worth noticing, namely, that his results are somewhat affected by the large amount of feed-heating used, the feed-water being heated up to 240° F. by the exhaust steam of the feed-water engines. These feed-pumps, of course, are ordinarily frightful steam users. So long as they are used in the form which is common, it is well to employ exhaust steam in heating the feed. But this shows not only merit in the whole installation referred to here, but simply the frightful waste of steam used in the feed-pumps. He says in another place that the use of this exhaust steam for feed-heating saves about 1¼ per cent. of fuel; which is simply another way of putting this fact, that the waste of steam in these feed-pumps is most extravagant.

With regard to Mr. Crompton's paper, I agree with him in recommending fire-brick lined furnaces when one aims at very high economy, and particularly in his insistance upon the diminishing of the quantity of excess air introduced into the furnace. That operates in two ways, directly in reducing the percentage of heat wasted by the discharge into the chimney, and again in making it more easy to get a much greater perfection of combustion in your furnace—which is important, not only with low-class fuels, but particularly so with all kinds of mechanical stoking.

Mr. Appleby.

Mr. F. J. Appleby: I am surprised to find in Mr. Crompton's interesting paper no reference to what may be called the latest system of utilising cheap fuel. I think it is one well suited to the fuel of the third class—that is to say, the small and earthy bituminous coals of the North. The system combines efficiency with economy. I refer to the use of powdered coal which, since the time of Mr. T. R. Crampton in 1873, seems to have been left alone until 1892, when it was again taken up in Germany, and has reached its highest development there. The powdered coal used in the present apparatus differs from coal dust in that it must be reduced to such a state that there is only about 3 per cent. residuum left on a test sieve of 7,000 holes to the square inch. Of course that requires very different handling from coal dust, which would perhaps all pass through 900 holes to the square inch. To ensure the success of the system three essentials must be attended to: (1) A perfect mill to reduce the coal to this highly powdered state with absolute uniformity and without sieving. This has hitherto been a cause of trouble in Germany, but there is now a mill in England which fulfils the required conditions; (2) the firing apparatus must be such that the coal is passed in an unbroken stream into the combustion chamber, and it must be so arranged as to be held in suspension in the air current until perfect combustion ensues; and (3) there must be an arrangement for the continuous maintenance of a high temperature in the combustion chamber. That is provided for by lining the furnace for the first 10 feet with fire-brick in the manner to which several speakers have alluded. When these conditions are fulfilled the highest percentage of ash is no hindrance to the use of the system; indeed, in one works

in Germany they are using coal with as high as 45 per cent. of ash. The Magdeburg Society of Steam Boiler Users reported on tests made with this system an efficiency of 83 per cent. when an earthy lignite was used as fuel. Again, a four days' test of the Berlin Association of Steam Users with this system (in which no grate is required) showed from 18 to 23 per cent. of superiority over ordinary hand-firing with grates. A sugar refinery in Austria reports that they now save on their fuel bill 22 per cent. The system is considered by Mr. Schneider to be especially suited for large electric stations, owing to the latitude it affords for adapting itself to sudden requirements. With average care it ensures a perfect absence of smoke. The quantity of slag formed is very small, and only needs to be removed once in twenty-four hours. Considering the high price of Welsh coal, and seeing that you only have to pay 10s. or 12s. a ton for good small coal, and that the pulverisation of the coal costs only 1s. or 1s. 3d. per ton (in some places it is as low as 10d. per ton), I think the system is worthy the attention of all engineers associated with large steam plants. In an installation now erecting in the north of England 400 tons of coal are to be pulverised in every twenty-four hours, and they expect to sell the coal powder at 5s. a ton. But when the conditions of space allow there is no reason why each station should not do its own grinding. Mr. Appleby.

Mr. BRYAN DONKIN [*communicated*]: Mr. Holliday's paper I consider very interesting. The utilisation of cheap and small class fuels is, in my opinion, most important, but generally boiler grates have not sufficient area. I would suggest for the consideration of the Council of your Institution the appointment of a special Boiler and Fuel Committee to consider the following: The proposal to send out to many of the electrical stations in Great Britain blank forms for the chief engineers to fill in, so as to collect accurate information to put before the whole of your members. The names of the stations, when wished, could be withheld. The great point is to arrive at the boiler efficiency at the various stations. The *heating value* of the fuel and its approximate size should be always given, as also the type of boiler and grate, and the feed-water should be measured either by the best type of piston water meter or in tanks. The cost of the evaporation per 1,000 gallons and the cost per ton of fuel delivered in the stokehole should be added. The heating value of the fuel, if many samples had to be tested, could be ascertained more cheaply than usual, perhaps at 5s. to 6s. per sample. The analysis of the boiler gases is also most important to calculate the excess of air, and no boiler experiment is complete without it. Often 100 or even 200 per cent. excess of air and more is found. A gas analysis of this kind may frighten even some of the electrical engineers, but there is no doubt that the expenses would soon be covered by the saving effected in reducing the excess of air to a reasonable amount. The smoke question should, if possible, also be dealt with, and observations should be made every minute by means of the five smoke scale diagrams, as described in some articles of mine in the *Engineer* lately. The method of stoking should also be added, and whether by hand or by mechanical means. I may mention that here in Bermondsey, with our Lancashire boiler, Mr. Donkin.

Mr. Donkin. it now costs us with small coal, in pieces from $\frac{1}{16}$ to $\frac{1}{8}$ of an inch and dust, about six shillings to evaporate 1,000 gallons of water from fairly cold feed (about 60° to 70° Fahr.). In a general way it is important to point out that fuel should *not* be bought by the ton weight, but by ton of water evaporated. This method works well in some places, but the contractor and the engineer must of course give themselves a little trouble. Dirt, ashes, and clinkers will soon diminish if the contractor is paid by the water evaporated, and has to pay for carting all the incombustible matter away. Fuel is now bought with an unknown quantity of dirt and incombustible matter in it, and engineers should specify that the latter should not exceed a minimum percentage of the total fuel. I am of opinion that the way in which we now buy fuel is *extremely* primitive, and just the same as the method in use one hundred years ago or more. No limit is set to the percentage of dirt, the size of the pieces, or the heating value of the fuel. To adopt the proposed system would cause no real practical difficulty, although it may be considered by some to be purely theoretical. As an example, all this is much better done on the Continent. The Belgian Government, who purchase large quantities of coal for all their railways, have tests continually going on, which I have seen, and they answer admirably. A systematic Central Testing Station has been working for many years, and the experiments determine if the guaranteed heating value of the fuel, its size and the percentage of dirt, are according to contract. The coal or fuel is refused if the result of the test is not within the limits of the specified guarantees. More system and method are wanted. Coal is of course bought for the heat it contains, and not for its weight only:—so many "thermal units per pound" with a price per ton, say. The whole method of buying fuel is, in my opinion, wrong and founded on a false basis, and reforms are sadly needed. Difficulties, troubles, and opposition are of course to be expected, but there is great need for better methods on a standard basis. As Mr. Crompton has carefully pointed out in his paper, the fuel is the greatest item of expenditure in electrical stations. The evaporation by the many forms of the cheapest possible fuels in different localities should be given by stating the cost consumption per 1,000 gallons evaporated, and no doubt there is a large quantity of "slack," various dusts, coke small and large, small coal, briquettes, etc., that could be usefully burnt and at low cost. As these low-class fuels produce a large amount of clinker and incombustible matter, arrangements should be made to feed the fuel on the grate automatically, and especially to remove the clinker and ash in the same way. The smaller the fuel and the greater the amount of dirt in it, the larger the percentage of clinker and ash as compared with ordinary fuels.

I quite agree with Mr. Crompton's excellent remarks on page 66 of his paper, that in modern boiler shops the fuel, ashes, and clinkers should not be touched by the stokers. The whole method of bringing it from the yard to the grates and taking away the refuse should be automatic; and to do this properly with cheap fuel would necessitate large grates and probably external furnaces.

Mr. Huskisson. Mr. W. Huskisson [*communicated*]: As having a direct bearing upon the subject of the papers under discussion, the following details

Mr. Huskisso

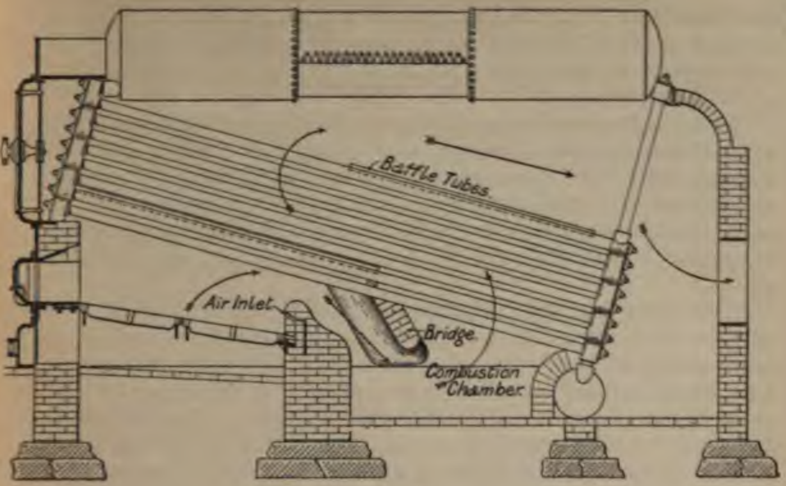

FIG. C.

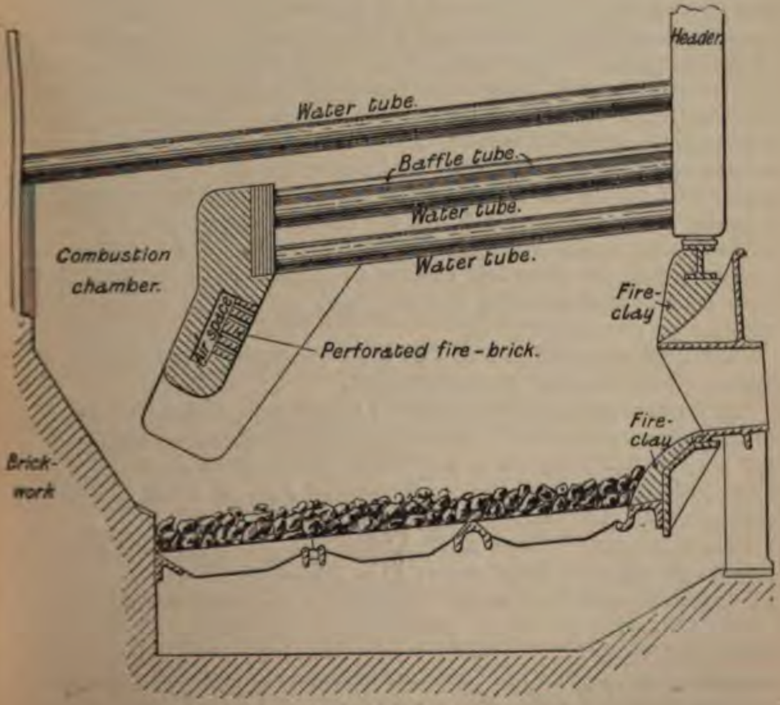

FIG. D.

Mr. Huskisson.

may be of interest of an arrangement designed to enable cheap and inferior fuels to be burnt smokelessly in water-tube boilers. The arrangement was perfected after about fifty full-power trials of six to eight hours' duration.

In the ordinary arrangement of water-tube boilers of having the tubes directly over the grate, the gases rise vertically off the fuel and strike the cold tubes. Owing to inequalities of the bed of fuel and (generally) an absence of mixing devices, the combustion is imperfect until the gases mix in the uptake, where active combustion takes place, provided the gases are at a sufficiently high temperature—if not, they pass off as smoke.

To remedy this, baffle tubes are laid on to the top of the second row of water tubes nearest the fire, one end butting against the headers, the other ending against the top of an inclined concave bridge, the concave part being inclined towards the fire, while it is supported by being arched below, the centre of the concave bridge lying in front of it, while the centre of the supporting arch lies at the back of it. The bridge springs off the sides of the furnace and is hollow, and the concave part of it is pierced by holes communicating with the hollow part through which hot air is forced, while a combustion chamber is formed at the back of the bridge.

The action is as follows :—The stoker always keeps incandescent fuel at the back of the grate and puts on green fuel at the front. The gases evolved from this fresh fuel pass over the hot incandescent fuel at the back, which brings them up to a high temperature. They are whirled round and lick the concave face of the bridge, hot air is supplied (through the holes piercing the bridge), a general mixing takes place, and perfect combustion ensues. The products of combustion then pass out through the contracted space enclosed by the top of the grate and the arched part at the bottom of the bridge, and into the combustion chamber at the back, and thence to the tubes and the uptake.

In this arrangement the radiated heat is not lost, and the gases do not strike the cold tubes and become so reduced in temperature that they cannot combine with incoming air, but perfect mixture and combustion is secured.

The illustrations (Figs. C and D) show the arrangement as fitted to Babcock & Wilcox and Niclausse boilers.

In practice the results are roughly : In one case, where four boilers of one type were fitted with this arrangement, Welsh coal costing 16s. 6d. per ton evaporated 10½ lbs. of water from and at 212° Fah., while poor local coal costing 7s. 6d. per ton evaporated 8 lbs. of water per lb. of coal, and with good stoking quite smokelessly.

The President.

The PRESIDENT : I have a letter from Mr. Holliday, who writes to express his regret at being unable to be present at this discussion, and his appreciation of the kind way in which his paper has been received.

Mr. Crompton.

Mr. CROMPTON (in reply) : I do not know whether I have to return thanks and reply for Mr. Holliday as well as for myself, but I cannot help doing so in some few instances because the two subjects are so closely associated. Although it is very tempting, I do not intend, at this late period of the evening, to be dragged off into side-issues. A great

many speakers, particularly on the first night, seemed to think this was a question of water-tube and Lancashire boilers and other matters which are entirely foreign to the question. My paper is on the use of cheap fuel, and certainly cheap fuels which require a large grate can be burned more easily with boilers having external grates; certainly the Lancashire boiler, with its long narrow grate, is not well suited for these fuels for that reason only. But I think it is quite outside this paper to discuss the question of the suitability of water-tube boilers as compared with other kinds of boilers. I am addressing an audience of skilled electrical engineers who have got a good deal beyond that kind of thing. There are a very large number in this room who have thrashed this subject out many years ago and have long since formed their opinions, and probably very correct opinions, and it would be flogging a dead horse if I were to try and re-open those old controversies. I only mentioned water-tube boilers in my paper because they are so largely in use, and because they are practically a standard type for power stations. Mr. Crompton.

I will take the speakers in their turn. Mr. Ferranti agreed with me generally, but called attention to one undoubted difficulty, and that is, that when you attempt to get perfect combustion in a combustion chamber the walls of that combustion chamber suffer; that is to say, the best lining material is liable to fuse, and constant repairs are needed. It was for that very object I proposed to use a readily-removed furnace which can be easily repaired. The form of bricks used is such that the arch can be replaced at a comparatively small expense. But I will take this opportunity of saying that Mr. Ferranti calls my attention to a point on which I did not dwell with sufficient insistence in my paper; that is, as to the character of the materials used for lining the combustion chamber. Many of you have wondered why fire-brick bridges and devices of that kind have in some cases proved very successful, and in other cases not successful at all. I have never seen it publicly stated that any one has observed the fact which I have noted, viz., the enormous effect the character of the fire-brick used has on the usefulness of the combustion chamber. When we deal with the material of combustion chambers we are dealing with something more of the nature of the mantles of incandescent gas lamps: we want a material which can take in and give off heat with extreme rapidity, and I believe that the researches which have been made in that class of highly refractory materials may be of use to us in developing combustion chambers to give far higher efficiencies than have ever yet been reached. I myself, in the limited experiments which I have carried out in my own works, have found differences amounting to as much as 100 per cent. in the effective nature of the surfaces which I used. I found that the softer surfaces, made with a material more closely resembling pipe-clay than the harder fire-bricks, not only were not so easily melted, but they increased the efficiency of the furnace as a means of preventing smoke and of getting high results and a high percentage of carbonic acid. I got as much as 100 per cent. improvement without any alteration in the form of my furnaces, but only in the materials used.

Mr. Stromeyer's remarks are to be received with the very greatest

Mr. Crompton.

respect. The early part of his remarks which referred to Mr. Holliday's paper greatly impressed me. I cannot reply to them: I take them from him. I refer to those in which he states that if the coal were pure, and the cost of evaporating the water were one penny, that if you had 20 per cent. of refuse it would be 1¼d., with 30 per cent. it would be 2½d., and with 40 per cent., 4½d. Those are very startling figures. They may be correct, and it is quite possible with the existing appliance such figures are obtained, but the whole object of my putting before you the difficulties which we encounter in the use of cheap fuel is to enable us to design something to get over those difficulties, so as to make the use of cheap fuel a real gain in economy. I described in the body of my paper the means by which I hoped that this could be done. The figures which I have given in the addendum are to some extent a proof that we *have* made an advance. Here we have a fuel with a very considerable percentage of non-combustible and a very high percentage of water giving a result comparable with the very best fuels. I think this shows that the ideas of those who have been working in this direction are promising. Although we may not, in constant practice, get such high results as were got on that six-hour test, yet I do not see why, when we have a machine-worked furnace, the results of a long test should not be quite as good as those of a short test. You know that the sole reason why the results of long tests with hand-firing are worse than those of short tests is, that the clinkering needed is slight until the six-hour test is over, so that the deteriorating effect of clinkering does not show itself on short trials. But when the clinkering process is continuous, as it is with the furnace I am advocating, it does not matter whether it is a six-hour test or a six weeks' test, providing the furnace works properly and does what it is intended to do—that is to say, continuously feeds itself with fuel and continues to deliver the clinker without any hand attention whatever.

I avoid what Mr. Stromeyer said about water-tube boilers, and also what Mr. Clerk said about them. Mr. Clerk, I think, makes a very considerable mistake. In the first place, in my paper I touched very lightly on the question of using gas in firing the boilers. I referred to Mr. Humphrey's paper, which was thoroughly discussed before the Institution of Civil Engineers, and which referred to a system now being tried on a large scale. I have not had anything to do with it myself. I only said in my paper that it promised well. But Mr. Blount answered Mr. Clerk very satisfactorily, I think, when he pointed out that Mr. Clerk had entirely neglected the effects of the hydrogen which would be obtained by the decomposition of the water used in those gas-producers. I had the great disadvantage of not seeing Professor Perry's figures until he showed them this evening, and I have not yet been able to follow them, having been obliged to listen to the rest of the discussion, and I do not feel myself in a position to tackle them now. I have no doubt, as Professor Perry said, that I can agree the figures with him, and I think the differences between us can be easily explained.

Mr. Boot's figures are extremely interesting, and will add very greatly to the value of the discussion on this paper when they are published in the Journal. I take it that he used the same boilers

throughout, with a very small alteration in the furnace for the different classes of coal; but that is not a fair way of comparing two kinds of fuel. They require considerable adjustments. The fire-bar adjustment, the length of fire-bars, and grate area must all be experimented with and adjusted before one can get the best results with each kind of coal; but I do not think that any short tests are of very great value. He has corroborated what I have said about the great loss by storage of fuel, and of course it is the case that the more finely the fuel is powdered the more rapid is the rate of deterioration. The cause of deterioration is well understood. Slow combustion goes on, and the combustible is oxidised and really increases the amount of earthy matter present in the coal. Mr. Crompton.

Mr. Geipel has given us some very interesting information, but I think he is a little unfair to Mr. Holliday. Mr. Holliday does really consider the capital cost and does put it down very clearly in his table, and I do not quite follow Mr. Geipel as to what further details of the capital cost he required. I quite agree with Mr. Geipel that it is a splendid thing to force boilers, as it reduces the capital charge very greatly. No man is more aware of it than I am. Mr. Miller, who spoke last time, will tell you that in one of the cases in which he and I were jointly concerned we sometimes used to fire a Babcock's boiler, which was rated at 250 H.P. up to 750 H.P. by injecting oil fuel on top of the Welsh coal, and thus carried the station over the peak of the load. It was more economical than lighting up two other boilers, and had no ill effect. But the usual thing occurred. Directly we began to use oil fuel in quantity the price doubled and trebled. In fact, there was no real price (it was only 2d. a gallon for a few weeks), so that practically the experiment was never carried further.

Mr. Lawson's remarks were practical, as they always are. On the subject of brickwork he has given us one or two valuable hints, which may not be known to many here, as to the way in which brickwork should be put into the boilers so as to reduce the cost of repairs. He has prepared a table which is really a continuation of the table which was published by me in 1894 with my paper. He has carried it further, into the total cost of the energy, and has pointed out that really a curve very similar to that drawn by Mr. Holliday on my table can be drawn on his table.

Professor Robert Smith thinks we electrical engineers have no monopoly of the energy question. I differ from him. I think we are the only people who put our backs into it. Until we began to discuss the cost of energy nobody knew anything about it. A few waterworks engineers did, but they kept it to themselves, and of course marine engineers did, but until we began to publish our accounts and vie with one another to cut down bills and find where the losses were located, very little was known of the cost of electrical energy. The effect of our special knowledge has been, as you know, that many manufacturing concerns all over the country are taking a leaf out of our book, and are putting down real power stations instead of going on in their old way having rows of Lancashire boilers and one large lightly-loaded engine *in an outhouse going round* at about fifty revolutions a *minute*.

Mr. Crompton.

Mr. Appleby spoke of powdered fuel. Undoubtedly there is a great future before it. It is well known that the late Mr. Crampton worked at it at Woolwich Arsenal, and others have worked at it on the same lines. I believe there are difficulties connected with it, but no doubt those gentlemen who have worked at it lately have got over some of the trouble. There is a question which I should like to ask Mr. Appleby: Where does the earthy matter, the incombustible, go to? If the fuel contains 20 per cent. of incombustible, and the whole is powdered, the combustible matter is burnt, and the remaining 20 per cent. of incombustible is either blown over the surrounding parish in the form of dust, or it stays in the boiler flues and has to be taken out at regular intervals. I am afraid that would necessitate a periodical flue-cleaning just as we have in blast furnaces, which means shutting down the works. I believe that was one of the troubles met with at Woolwich. It must not be understood from my remarks that I am throwing cold water on the idea, because it deserves developing. In fact, every scheme to enable us to utilise our cheap fuel to the best advantage deserves the encouragement of electrical engineers, who, in spite of Professor Smith, are more than anybody else purveyors of energy.

Mr. Holliday.

Mr. J. Holliday [*communicated*]: In replying to the very interesting discussion which has followed the reading of the papers by Mr. Crompton and myself, I would, first of all, desire to tender to the President and members of the Institution my very hearty thanks for the kind way in which my paper has been received and for my share in the cordial vote of thanks so freely accorded.

There are many points in the discussion to which Mr. Crompton has already replied, and these I feel are much safer in his hands than in my own; I will therefore confine my remarks to some points on which I have personal experience that may be of interest.

Mr. Crompton in his paper refers to automatic stokers, and of these I have had more success with those of the coking than with those of the spreading type. The coking stoker, however, is not suitable for varying loads on account of the loss of time that must elapse in order to secure the grate being covered with an increased thickness of fuel before the draught can be increased, and unless this is done the fire burns into holes and the output of the boiler is reduced instead of increased by the extra draught; I have used a coking stoker in boilers with a mechanically assisted draught, and in this case the difficulty has been a very real one. As affecting the cost of steam raising, I have found that over comparatively long periods of working, the reduction in cost of fuel and working expenses has been almost exactly balanced by the increased costs of maintaining the furnaces in good repair; whilst the possibility of the stoker giving trouble at critical periods is a further point in its disfavour. The fire-brick arches to these coking stokers were at first a cause of much anxiety, which was eventually much lessened by carrying the arches on independent supports above the level of the fuel, and fixing hollow cast-iron blocks below the springings of the arches through which the current of air admitted over the fires was drawn; these hollow blocks were easily renewed without disturbing the arches themselves, and stood considerably longer than the fire-brick

blocks first used. It is suggested that the semi-molten slag forms a flux for some of the constituents of the fire-brick, and rapidly reduces them even when it does not adhere to them and carry away considerable portions when knocked off. Mr. Holliday.

Mr. Crompton favours the Juckes furnace, of which I have had a number in my charge; these were used for heating and boiling liquids, and not for raising steam for power purposes. On one of these, with an effective grate area of 50 square feet, slack coal of a calorific value of 12,700 Th. units was burnt at the rate of 17·2 lbs. per hour per square foot of grate. It was found that with a chimney temperature of 622° F., 19 per cent. of the heat passed away in the products of combustion; the many careful analyses of the products of combustion on which the above result was based showing the percentage of CO_2 by volume to be 10·8 per cent. at the back of the grate, which was reduced by leakage to 8·8 per cent. at the chimney. This very large inleak of cold air seems inevitable with this class of furnace, and will, I think, never be sufficiently reduced to make it really economical. Maintenance of the metal portions is not heavy, but it is vital to secure the greatest possible uniformity in the size of the plates forming the links in the chain. Of its smokelessness and ability to deal with almost any class of readily ignited fuel there is very little question, but being a coking stoker it will not readily respond to a quickly varying load.

What I have just said about the composition of furnace gases will show that I do not agree with Mr. B. Blount as to what may be expected when analysing the products of combustion in a furnace. He is satisfied with 12 per cent. CO_2 as a good result, corresponding to an air supply of about 1·8 times the theoretical amount required, and I shall find it hard to make him believe that from the furnace of a boiler working with mechanically assisted draught I have found by three different methods, samples being taken simultaneously from two different parts of the smoke box, 17 per cent. of CO_2 by volume and no appreciable CO. One of the methods of determining the CO_2 in this case was by Arndt's Econometer, an instrument by which the varying percentage of CO_2 can be read direct as easily as the steam pressure is read on the pressure gauge. Another form of this instrument is the Dasymeter, and in my opinion some such instrument should be in operation in every large boiler-house. These instruments can be made self-recording. An account of experiments on boilers in which great advantages were found to follow the introduction of the Dasymeter will be found in a paper on "The Cost of Steam Raising," by Carl Jaufs, in *Zeitschrift des Vereines Deutscher Ingenieure* of the 31st of March, 1894. The economy to be obtained by the intelligent use of such an apparatus, especially during periods of light load, is considerable, whilst the extra steam produced by fires kept constantly in the best possible order during periods of heavy load is still more valuable.

Whilst on the subject of furnace gases, I may refer to Mr. Stromeyer's remarks on sampling. Of course this is the difficult matter, and everything depends on it, but the same remark will apply to the sampling of almost every substance submitted to chemical analysis, and the precautions which are recognised as sufficient in so many cases

Mr. Holliday.

ought not to miss the mark so entirely in the case of furnace gases as Mr. Stromeyer would have us believe. With all respect to his great experience, I would suggest to him that the great discrepancies he found between the results of the chemical analysis and his own economiser method may be due to the fact that as the water would take some time in passing through the economiser, the effect of the gases may not have reached the thermometers when the samples for analysis were drawn; whilst the fact that the averaged results of the two methods agreed so well seems to show that this was really the cause of the discrepancies. My experience is, that if furnace gases are to be analysed, it must be done on the spot and as soon as possible after the samples have been drawn, for even when kept over mercury it is difficult to avoid leakage. Extreme delicacy of manipulation is not required, as there is no value in any figure in the result of the analysis after the first decimal place.

The points that Professor Perry mentions with regard to the development and sale of energy are in close agreement with those which Mr. Bryan Donkin has communicated, and some information as to coal-testing stations may be found in a paper by Mr. Donkin and myself, published in vol. cii. of the "Proceedings of the Institution of Civil Engineers." Professor Perry has emphasised a point which I was anxious to insist on in the paper, viz., that many of the costs of steam vary with the amount of fuel burned rather than with the quantity of water evaporated, and I am thankful to him for the clear manner in which he has brought this out. The further figures that he gives will be studied with interest by every producer of electric current for public supply. His remarks on boiler circulation are suggestive, and the importance of this subject has been fully brought out by Mr. Geipel, whose figures showing the temperature of the water at the bottom of a Lancashire boiler must be startling to those who have not looked into this matter. I have on several occasions made experiments which amply confirm Mr. Geipel's figures. In one instance with a boiler of Lancashire multitubular type, having no external flues and therefore not heated at all underneath, in 4½ hours after the fires were started the water at the bottom of the boiler had only risen from 50° to 52° F., whilst that at the working level had risen from 50° to 196° F., in spite of the fact that to assist matters one-sixth of the total contents of the boiler had been run out at intervals through the blow-out tap and water of 180° F. pumped in to take its place. After trying without success several so-called circulators, Weir's Hydrokineters were put in, and by means of them the water in the bottom of the cold boiler was both heated and circulated by steam taken from the mains; in this way it was quite easy to heat up the lower parts of the boiler at the same rate as the upper parts. This plan has been followed during the past nine years, and the bottom seams of the boiler shells are in good order, and no repairs on them have been necessary. A still better plan is to employ forced circulation by means of a pump; this of necessity involves certain complications, but a small centrifugal pump and electric motor and the necessary fittings are not great extravagances compared to the saving of time and diminution of serious risks that would follow

Mr. Holliday.

their use. I should imagine that Mr. Geipel's circulating rib, in addition to a forced circulation such as I have described, would make a very efficient combination. Active circulation appears to commence with ebullition, it is therefore an advantage to keep the safety-valves eased on a boiler being put into steam, and thus allow circulation to commence at as low a temperature as possible.

The President.

The PRESIDENT: It only remains for us to pass a very hearty vote of thanks to Mr. Holliday and to Mr. Crompton for the papers which have given rise to this interesting discussion, which has now lasted for two evenings.

Carried by acclamation.

The PRESIDENT reported that as the result of the ballot the following gentlemen had been elected :—

Associate Members :

George Cornelius Berry. | Henry Cuthbert Buckmaster.

Foreign Member :

William Janus Schónau.

Associate :

Edward Henry Johnson.

Student :

Andrew William Barrett.

The Three Hundred and Thirty-Eighth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, December 14th, 1899, Professor Silvanus P. Thompson, F.R.S., President, in the Chair.

The Minutes of the Ordinary General Meeting held on December 7th were read and approved.

The names of new candidates for election into the Institution were announced and ordered to be suspended.

The following transfers were announced as having been approved by the Council, viz. :—

From the class of Associates to that of Members—

W. C. Mountain.

From the class of Associates to that of Associate Members—

Leonard L. Joseph.

Mr. H. T. Harrison and Mr. E. V. Graham were appointed scrutineers of the ballot for new members.

Donations to the Library were announced as having been received since the last meeting from Messrs. Whittaker and Co., to whom the thanks of the meeting were unanimously accorded.

The PRESIDENT: I have to announce that a very important piece of progress has been accomplished since the last meeting of the Institution. In pursuance of the policy which the Council of the Institution has had before it for some time, we have been promoting the organisation of local centres both within the United Kingdom and without. We have had three petitions in form from in each case more than fifty persons, acting members or eligible to join, for the creation of Local Sections respectively in Newcastle-on-Tyne and its neighbourhood, in Dublin for Ireland, and in Glasgow; and the Council to-night, acceding to the prayer of the several petitions, has created those three local centres.

A further petition from a smaller number of persons in Cape Town has been before the Council, and the Council has to-night decided to create a local section in Cape Town, so that the Articles of Association which were formulated with the view of carrying out this organisation eighteen months ago have now come into operation, and the local centres are actually created before the expiration of the year 1899.

It may be well that members should know at the earliest opportunity that the Council has further, on the recommendation of its Finance Committee, taken the step of transferring investments from its general fund, amounting to over £1,437, to the Building Fund, which now therefore stands practically at £7,000.

I have now to call upon Mr. Hope-Jones for his paper.

ELECTRICAL TIME-SERVICE.

By F. Hope-Jones.

The subject of this paper has, I believe, never before appeared in the Proceedings of the Institution of Electrical Engineers, presumably because electric clocks have until quite recently been considered little more than interesting toys, or at any rate have not achieved that measure of success which alone makes the wholesale distribution of time possible; the Electrical Engineering Profession as such has consequently had no occasion to deal with it.

In the first place, let there be no mistake as to the importance of the subject. The advantages of an organised service of uniform and accurate time make an apology for giving it an evening at the Institution quite unnecessary, provided it is not a mere dream, but, as I maintain, within our reach. Time-keeping is essentially one of those things that can be done much better by a Municipality or a Company than by the individual. What is every one's business is nobody's. There is not an argument in favour of the public supply of such commodities as electricity, gas, or water, which does not apply with equal or even greater force to the distribution of time. Anything like correct measurement of time is a delicate operation, so difficult indeed that absolute accuracy is impossible even with the aid of *carefully compensated* seconds pendulums

in our observatories. How then can we expect to do it for ourselves in every room and in every office, with clocks in which the length of the pendulum and the quality of the works are sacrificed to the ornaments of the cases? Yet we grumble at them unjustly, and go on using them—so true is it all the world over, but particularly, I fear, in England, that in the trivial and common things of daily life we are content with inefficiency, and submit to many of "life's little worries" through thoughtlessness or the want of energy and concerted action.

We have not made much progress in obtaining uniformity since Charles V. of Spain went mad in the attempt, and it seems strange that electricians have not accomplished it before, when we recollect that they have been at it since the beginning of the present reign, since the earliest days of telegraphy.

ALEXANDER BAIN began to think about it in 1837. In 1846 his system was in use between Glasgow and Edinburgh, and he had an attractive showroom of electrically-driven synchronous clocks in Old Bond Street at a date when it was necessary to devote a chapter in his description of them to an "Explanation of the electro-magnet."

Sir CHAS. WHEATSTONE and R. L. JONES'S systems were almost as early as BAIN'S, and C. SHEPHERD, some of whose work may yet be seen in Greenwich Observatory, installed a time-circuit of eight dials in the offices of Messrs. J. F. Pawson & Co., in St. Paul's Churchyard, in 1849. On the Continent we find that M. PAUL GARNIER (a veteran in the service of "Time," whom I had the pleasure of meeting in Paris last year) devised a system in 1850 which was applied to eighteen clocks in the Lille railway station in 1855; and again M. BREGUET, whose ingenuity provided seventy-two synchronous clocks in the streets of Lyons in 1856.

With such early and creditable pioneering work before us in the middle of the century, I think we should have made more progress before its close. Of that, however, you will be a better judge than an avowed champion of the cause, and it is only for me, in this short paper, to summarise and dispassionately review the various systems forming the steps in that advance, to point out carefully the conclusions *which a study* of their theory, and a practical acquaintance

with their working, leads me to form, and finally to describe my contribution to the subject and the system which I advocate.

In substantial agreement with Drs. TOBLER and SCHELLEN, M. FAVARGER, and other authors on the subject, I adopt the following general classification of electric clocks :—

(1) Independent, self-contained, self-wound clocks.

(2) Systems of clocks connected together by a line.

In such systems a "regulator," "controller," or "master" clock (whether self-wound or key-wound) is invariably used to send out electrical impulses (*a*) correcting or synchronising ordinary clocks, or (*b*), directly propelling the hands of "subsidiary," "secondary," "receiver," or "indicator" dials.

In Class 1 the main object is to save us the trouble of winding our clocks up once a week. When properly applied, electricity performs this operation better than we can do it, for a clock is an organism which likes its feed of power in small and equal instalments meted out to it with perfect regularity.

The first self-wound clocks were by BAIN and JONES, who applied electro-magnetic attachments to the bob of the pendulum, which, in obedience to contacts connected to the pendulum itself, attracted it to and fro. The wheel-work of the ordinary clock was retained, but the escapement modified to enable the pendulum to drive it, instead of the wheel-work driving the pendulum. In addition to the theoretical objection that the free action of gravity is interfered with when the impulses are applied to the lower end of the pendulum, there is the practical difficulty of obtaining a satisfactory working contact off the moving pendulum, and the fact that fluctuations of battery necessarily varied the impulse.

In 1856, M. FOUCAULT devised a most ingenious method of obtaining a firm contact from each vibration of the pendulum, which device was improved upon and adapted to a self-wound clock by Dr. HIPP in the same year, and has since become well known as HIPP'S "Electric escapement." It consists of a little pallet pivoted upon the pendulum and swinging freely over a pair of contact springs. The upper spring is provided with a notched block which catches the pallet and is *depressed by the pendulum* when the arc of its

vibration has fallen too low. An armature is fixed to the lower end of the pendulum, and the contact momentarily completes the circuit of a magnet placed immediately underneath it. I show you an example of this in one of the earliest instruments made by Dr. HIPP, and in the latest improved form devised by Mr. T. J. MURDAY for the self-winding integrating meter of Messrs. Johnson and Phillips. The same device has doubtless had many other applications since. I last saw it in use as a gas-engine regulator. HIPP'S electrical escapement satisfactorily disposes of the first difficulty I mentioned—that of obtaining a good contact off the pendulum, and almost meets the second objection by increasing the frequency of the impulses automatically and in exact proportion to their lack of strength. It is so successful that many Continental observatories use it in preference to key-wound regulators for accuracy of time-keeping.

A more common form of self-wound clock is that in which an ordinary 8-day timepiece has electro-magnetic power periodically applied to its wheel-work in place of a spring or weight, the electro-magnet or motor being controlled by a contact operated by one of the wheels of the clock-train. I show you the works of an American self-wound clock invented by H. CHESTERS POND as typical of this class. It is driven by a toy electro-motor which winds up a spring every hour. One naturally doubts the stability of its contact made off the going train when the spring power is at its weakest, the efficiency of such a small motor and its silence after running for a few months, and perhaps faults of this nature were contributory causes to the failure of the English Company which was formed to put it on the market in this country in 1885. Sir William Preece presented one of them to the Institution in 1888, and we may safely assume that the reason it is no longer in use is that the replenishing of the battery and the attention to the contacts has been found in practice to be more troublesome than weekly winding.

Other self-wound clocks which should be mentioned are those of SHEPHERD, BREGUET, VICTOR RECLUS of Paris, VAN DER PLANCKE of Brussels, WARNER of Waterbury, U.S.A., Lord KELVIN, Dr. LIPPMANN and Dr. AARON of Berlin, *but we shall* have occasion to refer to them later on under

Class 2 *b*. To these I could add the names of many other inventors, the evidence of whose ingenuity is only to be found in Patent specifications. With my notes before me of some two hundred British patents on the subject applied for during the last thirty years, it would seem that the idea of self-wound clocks was fatally alluring to the dreamer in search of perpetual motion who has done so much to swell the revenue of the Patent Office.

These inventions, however, do little more than save us the trouble of winding up our clocks, and, except in the case of electric meters, I should not be surprised were you to class them all—even the best of them—as misapplied ingenuity. It is true that in the case of HIPP and one or two others greater accuracy of time-keeping incidentally results, but if that cannot be communicated to and represented upon a number of dials its benefit is very limited. Inasmuch as it is impossible to make an absolutely accurate timekeeper whatever expense and care may be lavished upon it—and its error is necessarily cumulative—it will not suffice merely to improve the standard and quality of our ordinary clocks; we must strike at the root of the evil—*their independence.*

We therefore turn to Class 2, which sinks the individuality of a group of clocks by making them subservient to one master. Let us take first those methods in which the Controller sends out an impulse on a line to (*a*) correct or synchronise existing clocks. R. L. JONES accomplished this in 1858 by making contact every second in the master clock to control the vibration of subsidiary pendulums by means of electro-magnetic attachments to their bobs; and this method, improved upon and made by Messrs. JAS. RITCHIE & SON of Edinburgh, is in regular use in many of our observatories. It is, however, found incapable of application to a number of clocks in one circuit, though well adapted for keeping a small group of high-class regulators in sympathy, beat for beat. In this system it is necessary that the pendulums which are to be synchronised be regulated in the first place to considerable accuracy; as, of course, the more they are out of sympathy, the more will the electro-magnet be required to interfere with the free action of gravity. A temporary cessation of the seconds synchronising currents often allows a pendulum to get so far out of

phase that, when re-established, the electrical impulses directly oppose its swing and bring it to a standstill. After several years' trial with a clock at London Bridge, controlled from Greenwich in this way, the late Mr. C. V. Walker gave it up as impracticable.

Another class of synchronisers, far more suitable for wholesale application, is that in which a standard clock sends out impulses at longer intervals, usually every hour, to forcibly pull the hands of independent clocks into synchronisation by the armature of an electro-magnet fitted to each.

BAIN employed the stabbing action of a **V**-shaped notch (operating upon a pin on the minute-hand at each hour) for this purpose in 1843, and it is fully described in a pamphlet of that date, "On the Application of the Electric Fluid to the Useful Arts." RITCHIE revived this method in 1876, but renounced it in favour of giving the clocks to be synchronised a permanent going rate and stopping their hands or their scape-wheels by armatures interposed thirty seconds before the hour and liberated exactly at the hour. In the meantime, however, LUND was patenting a variety of devices for correcting the hands, and his name will always be associated with the Electro-magnetic Clip, which, in response to an impulse transmitted every hour, grips the minute hands of a number of clocks, pulling them forward if slow and backward if fast. An exhaustive paper on this subject was read by him before the Society of Telegraph Engineers in 1881, and we have to thank the Standard Time Co., Ltd., for the survival of this, the fittest system. Their central station at 19 and 21, Queen Victoria Street, E.C., is equipped with two steel and mercury regulators of the highest quality, which are kept very close to time by daily comparison with a special Greenwich time signal. Both of these regulators make a contact of one second duration every hour, but only one of them takes the load, the other being held in reserve and automatically switched in by a sentinel clock in the event of the working regulator stopping. The hourly contacts operate relays, which send out impulses in all directions over London correcting a large number of clocks, deflecting galvanometer needles or ringing single-stroke bells. If it were not for this service we should have nothing but the Greenwich-time signals supplied to a few of the leading clockmakers and dis-

seminated to the principal provincial post-offices over the telegraph lines from St. Martin's-le-Grand at 10 a.m. or 1 p.m. Since the inauguration of the Company in 1886, I understand that their rentals have been steadily increasing in spite of the difficulties incidental to overhead lines. As I shall have something to say later on in criticism of synchronisation in general, it is fitting that I should express the obligation we are under to this, the only system of Public Time Distribution in London.

It will be observed that in all synchronisers the complete key-wound clock is retained, the sole use of the line being to correct its errors periodically. The one advantage in such systems is that each dial has a life of its own and will continue to go if the line breaks down. But this argument in their favour only applies in these degenerate days when we value truth so little that we prefer a clock which goes even inaccurately to a stopped one. The greatest objection to synchronisation is the small use to which the lines are put. In telegraphy our energies have for years been almost exclusively concentrated upon increasing the transmitting capacity and the load factor of the line. Of course no such problem occurs in the electrical distribution of time, for we are not likely under any circumstances to require signals of greater frequency than 15 seconds, but the commercial argument is the same. Why use the line only once an hour to correct key-wound clocks, instead of using it every minute, half-minute, or quarter-minute to directly propel the hands, thereby dispensing with clock-works and the necessity of winding them up?

It is this consideration which forces us to the conclusion that for practical and wholesale distribution of time, we must look to that class of electric clocks referred to as 2 *b*, in which a controller sends out frequent impulses to directly propel the hands of large numbers of indicator dials. Let us now consider the work that has been done on these lines.

One would think that no mechanical problem could be more easy than that of rotating pointers synchronously in response to periodic contacts. Surely a simple step-by-step movement consisting of a magnet pulling a lever against a spring and a click on the lever engaging a ratchet wheel so as to pick up one tooth at each vibration, would suffice. Yet it is *not so. This has been the* most difficult problem

in the whole subject; in fact, it is one of the principal rocks upon which so many systems have split, leaving the shores strewn with the wreckage of fruitless inventions and failures, resulting in a deep-rooted prejudice against this use of electricity.

The simplest form of electro-magnetic time counter or "Dial movement" is shown in Fig. 1, in which A is the ratchet wheel to be propelled, carrying the minute-hand, B the rocking armature lever, C the propulsion click, and D the backstop. This movement fails because there is nothing to prevent the wheel A shooting forward more than one tooth. The momentum of a minute-hand is considerable, and its velocity is greatest at the end of its journey; it is therefore necessary to provide a "stabbing"

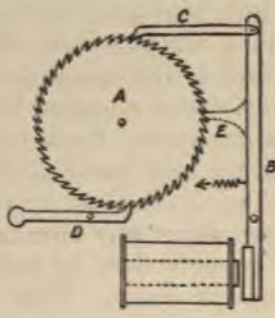

FIG. 1.

click to prevent it overshooting, which is shown in dotted lines at E.

The time counters of Messrs. ALEX. BAIN, PAUL GARNIER, RECLÛS, FROMENT, ROBERT-HOUDIN, DETOUCHE, MILDÉ, COLIN, LIAIS, WARNER, JOYCE, POTTS, STOCKALL, GENT, and others, are, with slight variations, identical in principle with Fig. 1. Theoretically this method is correct, but it has met with so little practical success that we must conclude it is a form ill-adapted for wholesale manufacture. I believe the difficulty lies in the mechanical accuracy necessary to make three pallets exactly in phase with the teeth of a ratchet-wheel when they are placed widely apart on the circumference. That there are difficulties which, rightly or wrongly, were considered insurmountable, seems clear from the number of less simple devices that have since been

invented to obtain the same result. If it were not for this surely the intricate and costly hydro-pneumatic system of CHARLES A. MAYRHOFER would never have been devised, nor even the POPP pneumatic system of Paris, for we cannot seriously admit the rivalry of pneumatics for transmitting small impulses to long distances. And again, innumerable complicated electrical step-by-step movements have since been devised, such as those containing the double impulsion clicks with reversed motions of MM. NOLLET, BREGUET, and DETOUCHE, and the weighted fly-wheel of VAN DER PLANCKE. In the latter system, the property of La Precision Cie., of Brussels, and in this country from 1893 to 1898 of the Electrical Time Recording Co., Limited, a sample of whose instruments is shown, the armature of an electro-magnet hits with a percussive blow an unevenly weighted balance-wheel, causing it to make one complete revolution, which is geared down through a train of wheels to produce a half-minute movement of the minute-hand.

Assuming that simplicity is commonly revered for its own sake, we must suppose also that the difficulties of making a step-by-step movement of this simple form that would neither trip nor overshoot, yet would be safely operated by a periodic current sent in one direction, drove some inventors to use polarised or rotary armatures and currents alternately reversed. Sir CHARLES WHEATSTONE in 1840, recognising also the difficulty of making reliable periodic contacts, generated alternate currents by means of the pendulum bob of his controlling clock, which was, in fact, a magneto-electric machine driven by an enormously heavy weight wound up by hand. The armatures in his dials revolved once for every complete vibration of the pendulum of the master-clock, and were geared to the minute-hand through a train of wheels. Truly this was an ideal system. Absolute uniformity of fifty clocks, only one of which requires winding up, and no battery is needed! But it was built upon a foundation of sand. It required that a time-keeping pendulum should serve also as a magneto-electric generator, and unfortunately that was impossible.

BAIN operated subsidiary dials from his self-wound clocks on similar lines, but with this important difference, that he recognised the necessity of a battery as the source of power; *and RITCHIE also, in 1873,* used alternate currents

to propel subsidiary pendulums, which revolved the hands upon their dials.

The rotary armature has, however, survived in the system of Grau, commercialised by C. THEOD. WAGNER, of Wiesbaden, which has received considerable support on the Continent, and is now represented in this country by the GENERAL ELECTRIC CO., LTD., to whom I am indebted for the models which I show you. Another alternate system which has had its share of success is that of Dr. HIPP (whose self-wound pendulum has already been noticed), commercialised by PEYER, FAVARGER & CIE., of Neuchatel. In this system the dials are provided with a polarised armature, which rocks an ordinary pallet staff engaging with a crown wheel as in a verge escapement.

Advocates of systems in which the direction of the current is alternately reversed will perhaps demur at my suggestion that their method had its origin in the difficulty of designing a satisfactory single-acting step-by-step motion. Two arguments in their favour can be advanced—(1) that the receiver dials are not readily susceptible to intermittent contacts, should any such occur in the controlling clocks; and (2) that no special care is required to make the action silent, owing to the movement of the armature being slow and not suddenly arrested by a fixed stop. I admit these advantages, but they constitute no argument against the more simple form of counter, provided a reliable one can be designed and a safe and non-intermittent contact can be obtained to operate it.

The production of such a contact has been another great stumbling-block, and innumerable methods have been devised whereby the wheel-work of a master-clock shall perform the duty. The difficulty of course lies in the fact that at the scape-wheel end of the clock train there is very little power available for such a purpose, and what there is can ill be spared from the primary and all-important duty of imparting equal impulses to the pendulum. In some cases, notably in this regulator movement of WAGNER, a separate train of wheels supplies the power required to send out the contacts, this train being let off by the going train at its side much in the same way as a striking gear is operated in an ordinary clock. The best method of obtaining a contact at *regular periods* off a pendulum clock that I have ever met

with is an unpublished invention of Mr. T. J. MURDAY, and I have his permission to describe it. In Fig. 2, A is a pendulum, whose vibrations are maintained by any means, whether electrical or mechanical does not now concern us, and B is a gravity arm bearing against it and carrying a pawl C, which rotates the disc D one step at each vibration. The free arm E is normally supported by the disc D, on which it rides backwards and forwards with each swing of the pendulum, until the notch in the disc allows it to fall,

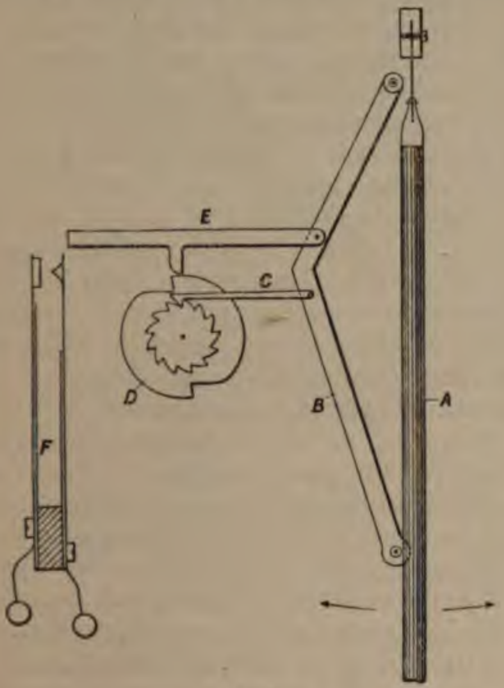

FIG. 2.

then it charges full tilt into the contact springs F with the whole weight of the pendulum behind it.

Having now reviewed the work of others and given, I hope, a clear idea of the progress achieved and the difficulties that still have to be overcome, I must here express my opinion as to which of the many suggested methods is destined, perhaps after further patient improvement, to give us House to House Time Service.

I *consider that the case for* "one-wheel" step-by-step

dials operated by a central clock is overwhelming on the grounds of simplicity and economy, provided that a good contact for transmitting the impulses and a reliable dial movement of that simple form can be secured, and my contributions to the subject lie in this direction.

In the system which I advocate the self-wound central or controlling clock has but one duty to perform, viz., to make and break an electrical contact every half-minute, and I prefer, therefore, to call it an "automatic timed-switch." Such an instrument necessarily requires the combination of the essentials of a good switch and those of a good clock.

I believe I am right in saying that in the systems I have named that combination has not been effected without one or other of the essentials suffering. Either the switch is inefficient through lack of power, or the safe-going and time-keeping of the clock are in jeopardy owing to this extraneous duty being required of it. In the instrument shown in Fig. 3, however, this is not the case. A is a pendulum driven by an escapement B in the usual way. The necessary turning force is applied to the scape-wheel by means of the weighted lever C, which in falling through a small arc communicates its power through a click and ratchet to wheel D gearing with the scape-wheel. E is an armature centred at F. As the weighted lever falls in its action of driving the pendulum, its lower limb meets the contract screw G in the tail of the armature, and the circuit of the electro-magnet and of a large group of dials in series with it is closed by the contact of these two parts. The weight is then thrown up and its momentum causes a quick break as the insulated screw H comes into action and the armature is stopped by the poles of the magnet.

This instrument has therefore the two essentials of a good switch—a severe rub and thrust and a quick break. It will be noticed that the switch consists of two moving parts, the armature which drives, and the weighted lever which is driven, and that *the entire energy required to keep the pendulum swinging is mechanically transmitted through the surfaces of the contact at each operation.* Thanks to this all-important principle, I have never known one of these contacts to fail, though some hundreds of them have been in use for several years under conditions in which a relay contact would have struck work in a month or two.

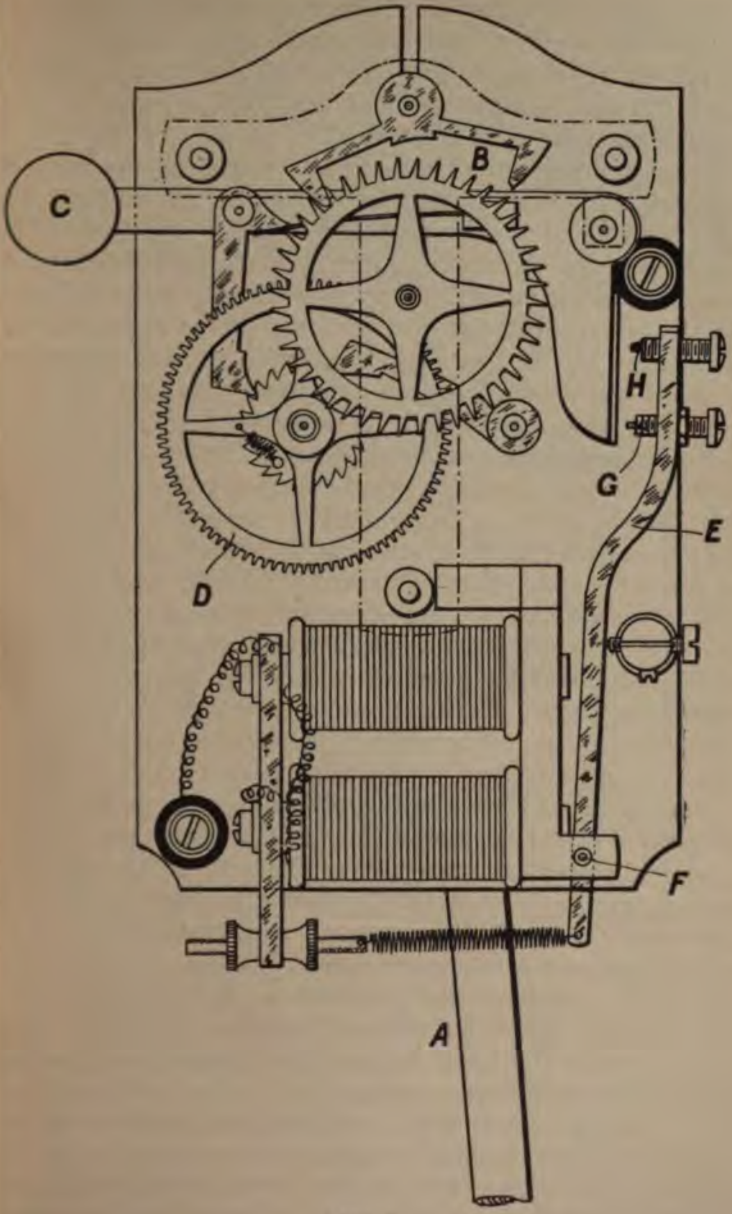

FIG. 3.

[Figs. 3, 4 and 5 are the subjects of patents granted to F. Hope-Jones and G. B. Bowell, *and are reproduced by permission of the* Synchronome *Syndicate, Limited.*]

Incidentally this automatic switching operation is used to provide a power of absolute constancy to maintain the vibrations of a pendulum by throwing up the weighted lever C every half-minute, and thus it also possesses the greatest essential of a good clock.

For operating any circuit of step-by-step movements the ordinary relay form of contact which has invariably been used before is to my mind quite unsuitable. Apart from the insufficiency of the rub and thrust, its duration has always been arbitrarily decided by guess-work. Obviously if the contact is too short, the least sensitive of the dials will not respond to it. If too long, there will be a considerable waste of electrical energy, and we must not forget that the exact duration required varies in every installation according to the time-constant of the entire circuit.

Now in this automatic timed-switch it will be observed that the duration of the contact is dependent upon an electro-magnet placed in series with all the magnets it has to control; its duration is, therefore, *in exact proportion to and dependent upon* the time-constant of the entire circuit. It is easy so to adjust the weight of the two moving members of the switch and the ampere-turns and self-induction of the electro-magnet which is employed to overcome their inertia, that the break cannot occur until the electric inertia of the whole circuit has been overcome, and every dial in it has had exactly what it wanted. As illustrating the perfect self-adjustment of the duration of the contact under all circumstances when performed by this instrument, let me instance its operation in the numerous time-circuits where an electric light supply is used as the motive power through an incandescent lamp as a working resistance; in these circumstances the switch automatically proportions its supply to the requirements of its circuit by breaking contact at the moment when the lamp filament has become sufficiently heated to allow the necessary current to pass. The gradual rise in current secured in this way, and the sudden break at exactly the right moment, is in every way beneficial. The former is conducive to silence in the action of the dials, and the latter ensures economy. Again, in time-circuits operated by a primary battery, as the internal resistance of the cells rises the duration of the contact will increase, and the dials will continue to operate in spite of a considerable drop in pressure.

Fig. 4 shows the step-by-step movement or electro-magnetic time counter operated every half-minute by the switch described. It is of such simplicity that I should feel diffident in bringing it so prominently to your notice, were it not that certain points in its construction have proved themselves to be of vital importance. The main wheel carrying the minute-hand has 120 rectangular teeth, and the armature lever carries a rectangular steel propulsion click limited in its upward movement by a fixed stop. Only one other click is provided, viz., the backstop, which is also a

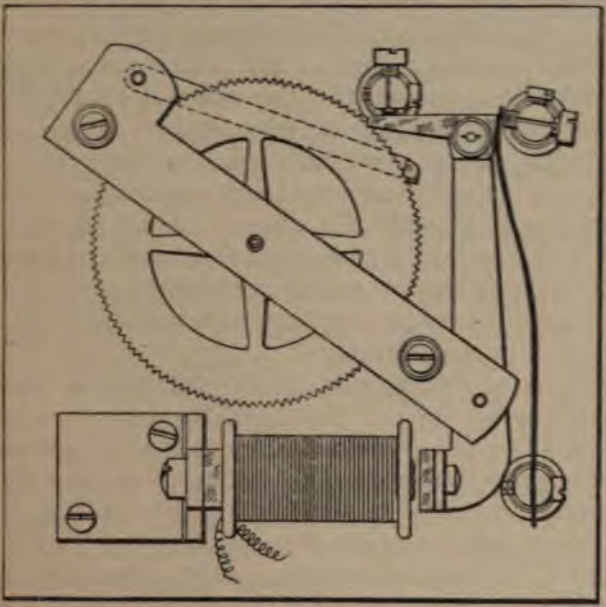

FIG. 4.

rectangular steel block at the extremity of a pivoted arm. The wheel is propelled by a flat steel spring bearing upon the heel of the propulsion click.

After reviewing all known forms of electro-magnetic time counters, Du Moncel lays down the rule that in addition to the impulse click and the retaining or backstop click, the wheel must be stabbed by a "cliquet d'arrêt," and, further, that the impulse click must always drive at a tangent to the wheel. We have ventured to transgress both these conclusions, and in doing so it appears that we have designed a movement which is more certain in action and more capable

of wholesale manufacture than any of its predecessors. By driving at an angle of 135° to the radius and adopting rectangular teeth, we can with safety apply a fixed stop above the propulsion click which will effectually arrest the momentum of the hands after their forward movement, thus accomplishing the object of the third click. The position of the propulsion click and this upper stop is of the greatest importance. If we drive at a tangent the slightest eccentricity of the wheel will, by varying the dimension between the circumference and the fixed stop, allow the click either too much space, so that it locks the wheel inefficiently, or too little space, in which case it will jam. The propulsion click in this movement is carried up against the fixed stop whether the wheel is eccentric or not, and runs no risk of becoming jammed, but remains perfectly free to slide out on the dead surface of the next tooth in response to an electrical impulse of any duration, provided it is not less than 100th of a second. Another point to be noted is that when only two clicks are used, and these are placed near one another on the circumference of the wheel, there is no difficulty in adjusting them nor any necessity for accuracy of workmanship.

This movement is particularly suitable for operating turret-clocks in which the hands are exposed to the weather. The usual turret-clock consists of an ordinary eight-day time-piece built upon a scale proportionate to the increased diameter of its dial. It is a difficult thing to build an accurate time-measurer of such a large size, and in spite of Lord Grimthorpe's invention, which prevents the wind pressure on the hands affecting the escapement, it is seldom accurate and always costly. Inasmuch as the only requirement is to revolve the hands at a given rate, it is obviously economical to accomplish this by so much brute force supplied on the spot and controlled by a time circuit or a self-wound electrical pendulum of reasonable size if no such circuit is available. It is of course necessary to provide a very large margin of power to overcome exceptional resistance, such as a gale of wind or the accumulation of snow up the minute-hand. Consequently a much larger size of our electrical step-by-step movement is required, and as the inertia of its parts is necessarily much greater, the duration of the contact of an ordinary time-circuit would

be insufficient to operate it. We therefore drive it by a separate battery in a local circuit controlled by a relay in the time-circuit. This relay is electrically interlocked with the large dial movement so that the latter can take its own time to complete its cycle of operations, the last of which is the breaking of its own local circuit. This arrangement is, I think, clearly expressed in the accompanying diagram (Fig. 5), and does not require further description. It will be noticed that the primary electro-magnet of the relay is in the time-circuit, and that a contact of the shortest duration

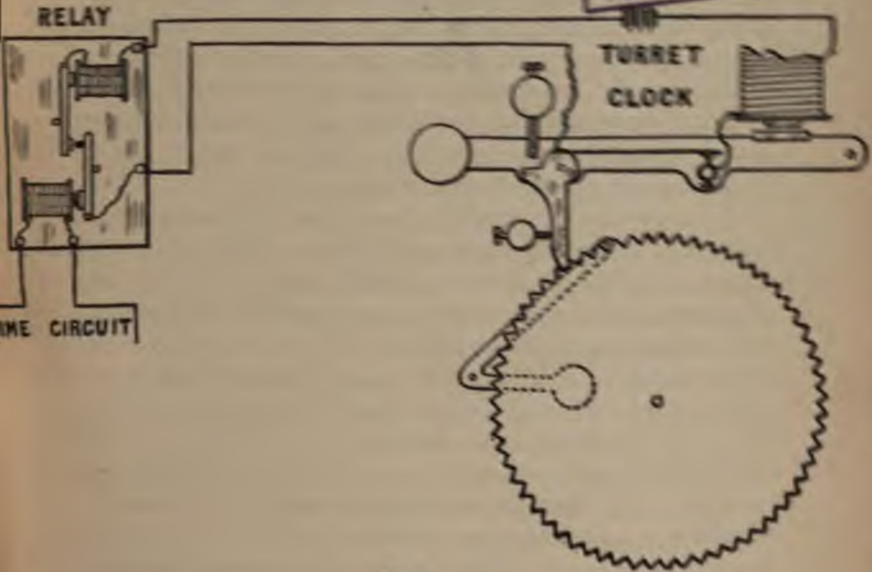

Fig. 5.

will suffice to start the secondary mechanism upon its work, which it will then perform in its own time. Even where a time-circuit is not available the great expense of the customary turret-clock movement may be saved by using an ordinary self-wound pendulum and escapement in mechanical combination with a large step-by-step dial movement; but the available space in this short paper prevents a description of it here. I, however, exhibit a model, which will serve to show that for this particular purpose an individual and independent self-wound clock is justified by its efficiency and economy.

Referring again to the small edition of the step-by-step

movement illustrated in Fig. 3, let us apply a rough-and-ready means of ascertaining the minimum duration of contact to which they will respond by putting a few of them in series with a vibratory interrupter. I take an ordinary electric bell for this purpose, and, removing the bell, adjust the hammer to a periodicity of about 25 per second. You will observe that the dials in circuit with it duly revolve at the rate of 12 hours per minute, and that whenever I break the circuit they stop at exactly the same half-minute, having kept perfectly in step. This test is of course unnecessarily severe, and it leads me to ask in all seriousness whether, when such step-by-step dials which have not been specially designed for rapidity will work synchronously in response to such rapid and imperfect electrical impulses, they will not serve to distribute time in a wholesale manner from house to house when controlled by a properly equipped central time station.

In such an undertaking we must, before all things, realise the enormous responsibility that public time-service carries with it. With our present method there is at any rate some security in numbers, and knowing that no two of our ordinary household clocks ever agree we only expect approximate time, and refer to our watches when greater accuracy is required. In an electric light service a breakdown betrays itself immediately, but in a time-service the stopping of one or more dials is an unannounced and insidious evil. Perfect synchronisation and immunity from breakdown is therefore necessary in any system of Electric Time Distribution. There is, however, no need to starve it. A hundred pounds or so would equip a central station lavishly, and, as the earning power of the lines is great (enormous when compared with systems of synchronisation or correction), they should be laid as carefully as electric light cables.

Lest we be tempted to allow considerations of economy to outweigh those of security, let me quote Antwerp as an object lesson. For about fifteen years endeavours have been made in that city to work a hundred street-corner dials on overhead lines radiating in all directions from a central time station, and earthed at their extremities. It is true that their step-by-step movements and the switches to control them were partly at fault, but no circuit could be

considered safe which a storm might interrupt and a falling telephone line might short-circuit. The Antwerp installation has now been abandoned.

Several suggestions have been made for utilising existing electric light networks for time service, but though interesting they are impracticable, and I must therefore deny myself the pleasure of dealing with them here. In the equipment of a central time station, it would be wise to provide two automatic timed-switches (such as those described in Fig. 3) and a sentinel switch of a simple form, of which I show you a drawing, to transfer the load in the event of the one in operation stopping from any cause. They would carry all the current required in an area of several square miles, the spark being of course shunted through a non-inductive resistance. It would be convenient to use low resistance magnets, and to put any number from, say, 50 to 100 receivers in series. The switch operates several such circuits in parallel. I think it would be unwise to risk the safety of time mains by allowing them to circulate in any building. I would, therefore, confine them to street clocks and relays placed in similar positions to meters, from which sub-circuits in each building could be operated. An ordinary relay, however, would be quite unsuitable to such a purpose; instead, we should use the pattern I show you, in which the duration of the contact is dependent upon the electrical inertia of the circuit it serves, and so designed that it refuses to work at all unless the battery power in the sub-circuit is sufficient to run its dials with safety. Thus responsibility for failure in local circuits would be decentralised, and a glance at the relay would show whether the fault was insufficiency of the local battery or a break in the local line.

Once a reliable time-service is established we shall recognise its utility for many other things besides turning the hands of our clocks. It will be required for operating tally clocks and watchman's watchers in factories, for ringing bells at pre-arranged times in schools, for speed-recorders in engine rooms, for automatic cut-in and cut-out switches for arc lamps, and last, but by no means least, to enable us to supply the most simple and efficient form of electricity meter imaginable.

Is it possible that such a simple method of electrical

distribution of time will suffice? I maintain that it is, provided the principles upon which the dial movements are designed and the electrical impulses are produced and distributed are correct. You will tell me that key-wound clocks are reasonably serviceable, and that, thanks to the accumulated force of centuries of industry and millions of capital, independent timekeepers can now be bought for 1s. 6½d. each. You will say that the vested interests of the clock-making trade are too powerful to admit of such rivalry. But to this I reply that the best is bound to win in the long run, and that one wheel giving uniformity and accuracy without weekly winding is better than the five or six wheels, the escapement, and the pendulum of an ordinary clock which requires weekly attention.

With a capital outlay of only a few pounds, and without organisation, already several large blocks of offices in the City have this time-service installed, the tenants gladly paying £1 1s. per dial for the first year and 10s. 6d. per dial per annum afterwards, and even at these low figures the business offers tempting prospects to the financier. At such a popular price it would not be unreasonable to expect that electrically propelled dials will be required in 50 per cent. of the offices in a busy district of the City, Greenwich Mean Time being guaranteed, and no charge being made for erection in addition to the rental. Further, the tenants would be spared the inconvenience of the weekly visits of the clock-winder. We must not wait for the municipal authorities to establish a public time-service in the streets, for they never yet in this country took the *rôle* of pioneers. It is not sufficient for them that the majority of the more important towns of the Continent have for years considered street-timing as much their duty as street-lighting and street-cleaning, particularly as existing systems have not been uniformly successful. Private enterprise must lead the way. The commercial considerations have been carefully looked into, and the existence of a demand for such a service has been proved. I believe I have demonstrated by theory and practice that these instruments are capable of supplying it, and that it now only requires the Electrical Engineering profession to take it in hand to establish public time-service on the same firm footing as *electrical light* supply.

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Mr. A. J. LUND: It would ill become me to say anything derogatory to the very interesting paper to which we have listened to-night, and after the kindly terms in which the author has spoken of me and of the system with which my name has been so long associated, if I make any remarks, they will rather be touching upon points in which Mr. Hope-Jones and myself would be equally interested, than depreciatory of the author's system. Mr. Lund.

First of all, I demur to the way in which he divides up the kinds of electric clocks. I doubt if the division he makes is one which will be readily apprehended by the public generally. I think it would be better understood if they were divided into "Impelled Clocks," "Controlled Clocks," and "Synchronised Clocks." Those are three descriptions which are readily understood. The Impelled Clock is one which, as in Mr. Hope-Jones' system and others, is driven by the current itself. The Controlled Clock is one which is controlled by the pendulum. When the clock goes the pendulum is not allowed to go wrong; it is made to go right; and therefore, by controlling the vibrations of the pendulum, you control accurately the time of the clock. The other kinds of clocks are those with which I have myself been associated for nearly twenty years, namely, Synchronised Clocks. The object of these clocks is to have an independent timekeeper which, whatever happens, would never be worse than an ordinary clock, which certainly ought not to vary by more than a very small part of a minute in a day. The object is this: As the clock goes round, the time current is made to clip the minute hand and set it exactly right every hour. Two of the advantages of the system are these: First, you are not without the time if the line breaks down, and if the clock is fairly well regulated you certainly, even then, ought not to be half a minute out after twenty-four hours. Another advantage is that, supposing that there be a break-down, and that for three or four hours the time-signal fails, when at last it does arrive fifteen out of, say, twenty or thirty clocks on the circuit would probably be put right by it, and then the circuit goes on as usual. In impelled clocks there is the corresponding disadvantage that, supposing your line breaks down, the hands are most likely at different parts of the dials, according as you are at one side of the break-down or the other. If that break-down were on your line, the clocks on this side of the earth would continue to act, whereas those on the other side of the earth would break down, and you would be obliged, in spite of not liking the services of the clock-winder, to send somebody round to set the whole of them right to some particular minute, in order that they might all start off again.

With regard to impelled and controlled clocks, some years ago my firm had the control of the whole of the Post Office clocks in London. About the time that our contract was expiring there was an electrical step-by-step system of clocks put up (I do not know by whom) at Mount Pleasant. I was, however, soon telegraphed for to wind up the ordinary clock in one of the rooms, and to disconnect the clock which was going step-by-step, as the continued click of the latter was too disturbing to the occupant of the room. Even after this, for three months, I continued to receive telegrams to wind the ordinary clocks, because the step-by-

Mr. Lund. step clocks had broken down. This was necessary in order that the office might not be without time.

The question of battery power is one of which perhaps Mr. Hope-Jones has not had the experience which I have had. To find a battery which will admit of constant use is a very difficult matter, and even if we use it only once an hour we find that it soon breaks down. But when you come to take current from batteries every half-minute, and have only half a minute to allow them to recuperate, you will want something better than a Leclanché battery before you will be able to keep the clocks going and be quite sure that your battery will not break down.

One word about Mr. Pond's system, which was introduced here some years ago. The author remarks that all synchronised clocks are supposed to be key-wound, independent clocks; but Mr. Pond's intention was to break away from that: he had a distinct system of synchronisation. His idea was to have self-wound clocks which would wind themselves by means of a local battery, so that each clock was an electrical clock; but, not being all electrically connected, if one broke down the others did not necessarily break down also. Then he connected all those clocks upon a synchronising system in order to correct any errors in the going of the clock.

Then, as to the duration of those clocks, which has also been touched upon in the paper. I have had one of them going in Fitzjohn's Avenue for seven or eight years at least, and the battery, instead of having broken down, I am glad to say, has been in the habit of lasting from two to three years before it required to be renewed. I should like to point out that, in my experience, local batteries should not be put in cellars or cupboards. You cannot put them in a better place than in a corner under the brickwork of the window, out in the open air, exposed to all the variations of temperature. A battery placed there will last six times as long as it would anywhere else.

The Silvertown Company, at the time I was floating Mr. Pond's patent in this country, took much trouble to get a battery which would be suitable for my purpose, and succeeded in producing a very small contact battery which would go inside any ordinary dial case, and I have known them last three years, winding the clock hourly, before they broke down; although in other cases, of course, they have not lasted so long. My assistant has one in his house which has been going ever since it was started, seven years ago. Some of you will know of an interesting attempt made by the late Mr. De La Rue to have a clock going in his works controlled from Greenwich. I think it was put in the same circuit as Mr. Walker's clock, referred to by the author, at London Bridge. The idea was to have a pendulum electrically controlled every second, or at each swing of the pendulum, by a current sent from Greenwich. But Mr. De La Rue got so tired of the break-down of the impelled clock that he had the impelling process taken away and a synchroniser put on the clock. I am not sure if the synchroniser is there to-day, but anyway the impelled clock had to give place to the synchroniser.

Having touched upon this question, I must refer to Mr. Hope-Jones' statement that one great objection to synchronisation is the

small use to which you put your lines. He forgets that if you put your lines to small use, you put your battery to small use; and if you put your lines to great use, you put your batteries to great use; and therefore, while you cannot break your lines down by sending a battery current through them, you can break your batteries down by using the battery power through the lines. I think that will be found a very serious matter. The author says that we prefer a clock which goes inaccurately to a stopped clock. That is so. We prefer a clock that shall go and show us the time within reasonable limits *to no clock at all*, because *if the clock stops it ceases to be a clock.* A remark was made in the paper about the wrecks strewn upon the shore wherever persons had tried to operate these step-by-step clocks. They are everywhere, and I can present the lecturer with not a few. I have worked at the subject, and I have known what it is to be disappointed. I can only say that I hope his system will not suffer with the rest. But these wreckages have produced a serious prejudice in the minds of the British public against step-by-step clocks, or rather I should say that, as these things produce so many wrecks, I fear the public will decline to undertake the use of a system which most likely would only add another wreck to the many that already exist. Mr. Lund.

Mr. HAYDN T. HARRISON: Mr. Hope-Jones' paper has interested me particularly, because I was connected as electrical adviser with the company which is synchronising clocks all over London on Mr. Lund's system, and during that time I had a chance of finding out exactly what the faults were and to what the failures were due in electrically synchronised clocks. As Mr. Hope-Jones says, the lines we employed were only used once an hour to correct the time, but they were overhead lines, and we found that it was as much as we could do to keep them in order, the intervals between the hours of synchronisation giving an opportunity for repairing them. It would be hopeless to talk about using clocks in which the impetus is sent out every half-minute, if you intend to employ overhead lines. I am sure that in London, at any rate, it would prove a failure. Then the question comes as to whether it would be possible to use underground lines. I have thought seriously over that question. Of course there are all the difficulties and troubles—which are not to be despised in London now—of getting permission to put down underground lines; but granted the permission, would it pay you to lay down a line which has perhaps a potential difference of 200 volts on it impressed by the battery, and the large self-induction which, with all the magnetic relays proposed, would cause the potential to be very high at the break on every occasion? Would it pay you to lay a line which requires all that amount of insulation for the simple purpose of actuating clocks? That, I think, is the question to be put on a financial basis before any one attempts to propose a universal system of electrically actuated clocks. I am seriously doubtful of it, at the prices named in this paper. Moreover, I do not think you would find it would be universally taken up on those particular terms, and if you reduce the terms you have still less chance of paying the interest necessary on the monetary outlay on the underground wires and other plant necessary for that class of work. For Mr. Harrison.

Mr. Harrison. these reasons I do not think that on this basis it could ever be made a financial success, although it would be very pleasant to know that our clocks are keeping somewhat near standard Greenwich time. I think the system of hourly synchronisation, which at present prevails, and which is very successful, is one that will always continue, and for which I believe there will always be a demand; and if it can only be worked, as I fancy it is now being worked, with a little more expenditure on the lines, subscribers would come on very rapidly, because they would know that whether their clock is working correctly or not they can be sure of a signal every hour correcting the clock and giving them the absolute Greenwich time, which is obviously particularly useful to scientific people or clock-makers, or people who have to go by Greenwich time.

The ingenuity which Mr. Hope-Jones has displayed in some of the mechanisms he has put before us has struck me as being marvellous, and particularly his standard clock for sending out the half-second impulses, but I am afraid that the actual dial movements would suffer in the course of time from a good deal of wear and tear, because, as everybody knows, water dropping continually will wear away a stone, and so that continuous series of strokes on the wheels will no doubt, unless those wheels are made of steel, in course of time wear the dials; but, perhaps, as dials are cheap that would not matter much.

Mr. Raworth. Mr. J. S. Raworth: When we get rival inventors of clock systems together we discover that each of them would rather that we went on using the old-fashioned clocks than that we should use the modern system of the other inventors. I should like to look at this matter from not quite so pessimistic a point of view as Mr. Harrison. He is of opinion that this system cannot be made to pay on account of the great difficulties of distributing the current. There is no doubt, however, that it does pay already in some places. Take the case of large hotels with 400 or 500 rooms: it is not until you have lived in one of them for a week and found how very inconveniently the clock-winder times his visits that you really begin to appreciate the advantage of an electrically-propelled clock. I have had some experience of these clocks in Paris. There is one thing about which I wish Mr. Hope-Jones to assure us before the discussion is finished, and that is as to the noise. When you go to bed in Paris you are worried by the intermittent "tick" of the electric clock. You start and wonder what it is. Time after time you are disturbed by it just as you are dropping off to sleep, and finally you get out of bed and shut off the switch and you have done with it. I think that will be one of the difficulties which Mr. Hope-Jones will have to surmount.

When I came into this room I thought I had nothing to say on clocks, but when I saw the diagrams I remembered that I went through all this experience some years ago in trying to make ship signals synchronise by electricity. If I had only had Mr. Hope-Jones' paper at hand at that time, I have no doubt that my experiments would have come to a successful issue instead of being a total and complete failure. I hope that the gentlemen who are working on these lines will study

that action very carefully, because it is very ingenious, and so far as I can see it ought to be perfectly reliable. Mr. Raworth.

Mr. A. H. BATEMAN: I should like to say a word or two, not so much from the scientific as from the practical side. I started making an electrical clock in my earlier days, and have watched clocks of this type with much interest ever since, and nearly two years ago that interest culminated in my finding accidentally one of the early pamphlets of Mr. Hope-Jones. I did not then know the gentleman at all, but as I was inquiring about a good clock for a parish hall at Lewisham, I instructed my own mind as to this new system, and it ended in my buying a clock, and then two more, and then a fourth; and I have been watching with scientific, horological, and electrical interest the performances of these clocks, which have now been going for nearly two years—an 18-inch dial in the parish hall; a 12-inch dial in the club room attached, some 300 feet away; a 10-inch dial in the artists' room; and a 4-inch dial in the kitchen. They have gone on one set of batteries—Siemens' Obach batteries—absolutely well. They have kept most admirable time, and on only one occasion to my knowledge was there anything disagreeable about them. That was when the "click" which the last speaker described occurred in the clocks on the occasion of some private theatricals, and the hall-keeper had to stop the pendulum. I circumvented the difficulty by fastening two pieces of old felt carpet on the wall behind the clock-case, that is between the clock-case and the brick wall. Since that there has been no more trouble, for the clock is quite inaudible. When I went to report to Mr. Hope-Jones about this he showed me a clock that he had recently brought out, which is absolutely silent. Therefore that difficulty can be overcome. I ought to mention that in one instance somebody knocked the kitchen clock off the nail, but the other three clocks continued to keep perfectly good time, while even the clock itself, although hanging from its wires, was also going true to time. Its being out of level did not matter at all. I venture to think there are very few ordinary clocks which would have stood that ordeal. Mr. Bateman.

Mr. W. H. STOCKALL: There is, without doubt, a very big future for electric clocks, but much depends upon getting the right and proper system. With regard to Mr. Hope-Jones' clocks, I put my hand, before the meeting began, on the minute hand of one of the turret clocks exhibited, just by way of putting a little wind pressure on, and away went the hands for a quarter of an hour at one "click." That does not look as though the step-by-step motion were secured there. But there is a clock at Liverpool Street Station with four six-foot dials fitted with a new one-wheel, step-by-step, movement that has as yet only reached the stage of provisional protection at the Patent Office, and I will defy anybody, by putting a ton weight on to the hands, to move that more than one tooth at a time, although exposed freely to wind and to the dirt and corrosion inseparable from a railway station. Mr. Stockall.

Mr. Lund referred to the system of electrical clocks installed at the West Central Post Office. These were made by a Belgian firm, *The Electrical Time Recording Company*, and my firm installed the clocks for them. That system, from the time it was inaugurated, has gone to

Mr. Stockall.

perfection, and is still in existence, and at the present moment the Tothill Fields Post Office has not a mechanical clock in the place, nor has it ever had one since it was built. He then spoke about a gentleman being worried at one of the offices, and his having to wind the ordinary clock in his office because he could not bear the click of the electrical clock. I remember the incident very well. It was also in connection with the Belgian system, the clocks of which do make a nasty click, like those of Mr. Hope-Jones' system and many other systems. The gentleman who occupied the office was very irritable, and the clock was done away with. But the electrical clocks in all the other departments still go on and give perfect satisfaction, and remain under our control. Much stress has been placed upon the silencing of electrical clocks. I have them in my own home in every room, and they are as silent as can be. With a little rubber attachment they can be made so silent that you would not know there was a clock in the room at all. With regard to the magnitude of the system, when properly carried out, and by a definite step-by-step movement, I may say that at Liverpool Street Station and at Wolferton Station we have at the present time the whole of the station, signal-boxes, telegraph-offices, and booking-halls, all controlled perfectly and positively, and doing their work accurately and well; and the Post Office authorities are so far satisfied with our new system, that they have ordered their new premises at Mount Pleasant, where they have some 2,000 or 3,000 sorters, to be entirely fitted up with the same electrical clocks.

The most serious question for the whole system is the battery power required. I notice that the clock exhibited, which has 5-ft. hands, has seven dry cells to drive it. Fortunately we are driving ours with one; but at the same time, whether you have one or whether you have seven, they must in time give out. We clockmakers are doing our very utmost to introduce into the market a reliable, sound, commercial system, and we rely upon you electrical engineers to find us some sort of constant battery that really won't fail us in the time of need. I have read and re-read Mr. Hope-Jones' paper very carefully indeed, but can only say that, while thanking him exceedingly for it, it does not appear to have advanced beyond what he told me three years ago at the Horological Institution.

The President.

The PRESIDENT: Some time ago I had occasion to go over the new building of the Institution of Mechanical Engineers, and I found that the whole of the buildings were fitted with Mr. Hope-Jones' clocks. I also, not long ago, was invited to pay a visit to the new building of the Surveyors' Institute, and there also I found Mr. Hope-Jones' clocks installed all over the building. Is there any one here who knows whether clocks in those two places have been giving satisfaction?

Mr Worthington.

Mr. EDGAR WORTHINGTON, in response, said: At the Institution of Mechanical Engineers, where we put in these clocks about twelve months ago, although at first we had a great deal of trouble, due to an unfortunate bit of wire-laying, which had nothing to do with the clocks, I cannot say that they have gone absolutely perfectly, but they have given almost perfect satisfaction, and I believe Mr. Hope-Jones, who pays us occasional visits, is finding out and putting right the two

or three little defects, where one clock dropped behind, for instance. We have a master-clock situated in the cool cellar and about a dozen other dials, all driven from the 200 volt lighting mains. The question of noise has troubled us a little, but the clock which gave the most trouble in this direction is now silent, and during the last few weeks they have been going well. The Secretary of the Surveyors' Institute, Mr. Rogers, told me that he is satisfied with the installation in their building. Mr. Worthington.

Professor AYRTON: I should like to ask the author whether the rate of going of the master-clock is found to be at all affected by the time-constant of the circuit to which he alluded. Is there any intentional interval between the lifting of the weight and when it begins to depress the wheel? The weight falls and makes a contact with the armature when it has fallen by a definite amount. Then how long it takes to be raised depends on the battery and the time-constant of the circuit. Supposing I were to put, say, self-induction in the circuit and rather prolong the time the weight takes to rise, would not that tend to make the master-clock go a little slowly? Or is there in this arrangement an intentional interval of time after the raising before the weight begins to introduce a driving force? Some fifteen or sixteen years ago I had to test an electric clock in which there was a very similar contrivance. In that clock, if I remember rightly, there was an intentional interval of time between the falling of the weight, that is to say before the weight began to exert the driving force and its being lifted; so that although the lifting was commenced at a given point, the pendulum went on alone driving the clock for a short interval of time. Consequently, whether the weight was lifted rather quickly because of the battery being strong, or rather slowly because the battery was weak, or because there was a good deal of self-induction in the circuit, the time when the weight began to exert the driving force was always exactly the same. I think probably, however, the very ingenious arrangement which Mr. Hope-Jones has employed to make contacts was not employed, and that there was a more old-fashioned method of making the contact. I am interested in the point I have mentioned because I had to make a report to the Council of this Institution on that particular clock, and it struck me as being very interesting from possessing the ingenious device to which I have referred. Professor Ayrton.

Mr. G. W. FRODSHAM: I have not had the paper long enough in my hands to study all the details, and therefore am not competent to pass remarks upon some of the minute points which are very important. The author made some apology for going into the subject minutely, but it is necessary to do so. The history of electric time-keeping during the last thirty or forty years may be briefly summed up. For many years it had been considered that an electrically-driven clock was not to be countenanced, and that an electrically-controlled clock was the best, that is to say, some clock which had in itself the power of going independent of the current. At the present time, when so many Institutions are using electricity in their buildings and there is a staff of electricians accessible, these views have been modified. Still, as a clock-maker and electrician, I hold that every clock should have in it some internal force independent of the current. Of course in Mr. Hope- Mr. Frodsham.

Mr. Frodsham.

Jones' system the current may be always perfect and reliable, but we know in practice how things sometimes fail. If we take that view, it is necessary to have some power within the clock such as that in use in the Belgian system, which is employed in many places with great success, I believe—although in Glasgow some were put up which gave trouble for a time.

The author mentions one system which is used in connection with his clock. It is that of sending the current to the houses and not allowing it to go through the wiring of the house, to avoid interruption of or tampering with the circuit. In that case the difficulty of attending to the local batteries, or to the batteries locally used in each house, or to the current turned on by the relays would still have to be overcome and still be a source of expense.

Of course, as has been pointed out, there is a certain amount of waste in not having the current always at work, but it can easily be made to do more duty by arranging that in a series of, say, fifty clocks, six different clocks should be brought under the influence of the current every ten minutes of the hour ; by this means a current of lower power would effectually do the work required. By a mechanical arrangement the clocks would themselves invite the visit of the current during a period which would range from a little before to a little after the time at which the contact should be made.

With regard to the necessity of going into questions very minutely, I may refer to a matter within my own horological experience. Some years ago I thought it would be useful to devise an instrument for observatory use which would give astronomers the opportunity of recording half-seconds upon a slip of paper such as is used in many of their instruments. With that object I determined to break a current every half-second by passing it through the escapement of the chronometer. I then visited Hamburg, Bremen, Dresden, Berlin, Vienna, and Geneva, in order to ascertain what was being done in this direction on the Continent. I found in one or two places that my idea had been partially anticipated, and eventually found it had been thought of by Professor Plantamour of Geneva. He had worked at the observatory and had discovered that the difficulty was, that the current passing through the escapement of the chronometer, which was a small spring lifted from a stationary screw, created an attraction between the spring and the fixed screw which altered the rate of the chronometer. He was therefore compelled to make two trains of wheels, one to keep time and the other to make and break.

Captain Acland.

Captain F. E. D. Acland : I think it must be a source of great satisfaction to Mr. Hope-Jones to have had so little real criticism on the points raised by him in his paper. Mr. Stockall, I notice, was particularly strong on the step-by-step movement, which is the main point of Mr. Hope-Jones' paper. I personally have been interested, as an amateur, in the measurement of time. I do not agree in the slightest with Mr. Lund. I think Mr. Hope-Jones has the power behind him to do away with the old-fashioned methods. I have in my *own house*, I purchased it from Mr. Hope-Jones over three years ago, *quite the* worst sample of installation that he can produce. There were

no two-dial movements the same. The controlling pendulum was very rough, and I put it up in an old case in my front hall, which is perpetually open to the garden. When I had controlled it, it went so accurately that after three months I could not detect any variation in the half-minute beat at all. There was no variation. From that day I never regulated it for nearly three years, and I will undertake to say that it is running to-day within the half-minute beat. It has stopped once, I admit, owing to my own fault. I went away for my summer holiday, and on my return found the clock case inhabited by a family of earwigs and spiders. I could, literally, have brushed off the controlling instrument a fair handful of dirt and dust. Owing to that the clock stopped. Captain Acland.

I have had a similar clock in my office for three and a half years, and was much troubled by the periodical "click" until I got accustomed to it. But within the last year I have purchased a movement which is so silent that when I put my ear to the case containing it I cannot hear it. My experience, which has been chiefly in gunnery work, has taught me that, in attacking a problem, when you come to a difficulty, the best way is not to invent new things to get round your difficulty, but to remove the source of the difficulty itself. If the noise is great, Mr. Hope-Jones and Mr. Stockall, and those interested in this class of electrical work, have got to remove the noise, and I am quite certain it can be done if the cause is discovered. I believe that Mr. Hope-Jones by his long and patient work is gettting down to the bed-rock of the matter, and I think the reason why in the early experiments electrical time-service was impossible, was that the knowledge of electricity twenty years ago was relatively so small. If electrical engineers do not overcome these electrical difficulties there is very poor hope for the future. I must congratulate Mr. Hope-Jones on the care which he has given to this paper.

Mr. W. Ellis, F.R.S. [*communicated*]: My experience in regard to the application of electricity to horological purposes was confined to the period from 1855 to 1874, when I had charge of the Time Department at Greenwich Observatory, after which I became occupied with other duties. A system of sympathetic clocks on Shepherd's principle had been set up in 1852; worked from a central pendulum clock, the pendulum impulse was given at alternate beats by the discharge of a small weight raised by action from a one-cell battery, the several other clock trains being driven, second by second, on Shepherd's plan, from a larger battery; the system was thus wholly maintained by electric action. In early times there seemed to be an idea that electricity should do everything, instead of using it as an auxiliary. I should have preferred, for the central clock of the above-mentioned system, an ordinary weight clock, making the necessary contacts for the sympathetic clocks, for as it gave the hourly time signals to the Post Office it was desirable to guard it from the consequences of any temporary accidental electrical failure. The system of sympathetic clocks, with some modification, still, I believe, exists. Mr. Ellis.

In regard to the *two systems of electrical* control that Mr. Hope-Jones *discusses, (a) the correcting or* synchronising of ordinary clocks,

Mr. Ellis. and (*b*) the directly propelling the hands of secondary clocks, I may say that, as respects the controlling of ordinary clocks, I had experience at the Observatory and otherwise of Mr. R. L. Jones' system of electrically controlling other clocks by action on their pendulums, and found the system very satisfactory. In one case in which we controlled a half-seconds pendulum on this system, the arrangement of magnet and coil was reversed, a small bar magnet being attached to the pendulum below it, the coil being fixed to the clock-case. The system was also applied to a chronometer beating half-seconds fixed to the eye-piece of one of the equatorials; here a small magnet was fixed centrally on the balance staff of the chronometer, being encircled on one side by a coil fixed to the chronometer plate. Mr. Hope-Jones seems to me to give an impression that clocks controlled on R. L. Jones' system require to be regulated to a greater nicety than is, I think, the case. The clock that Mr. Hope-Jones speaks of as thus controlled at London Bridge from Greenwich was not so worked; it had no pendulum, and its train was driven, second by second, from the central clock of the Greenwich system, as were the clocks within the Observatory walls. Its performance at this distance from Greenwich was not satisfactory, and it was after some years removed. Had it been a pendulum controlled on R. L. Jones' system, it would have had a better chance.

With respect to Mr. Hope-Jones' method (*b*) in which the distant clock depends entirely on the transmitted current, I sympathise very much with him in what he says as to the difficulty of contriving an efficient step-by-step movement, an obstacle that has no doubt retarded the introduction of such clocks. If he has overcome this practical difficulty he will have done a good thing, and I trust that it may be so. And even admitting that perfect clocks of this kind are possible, so far as their internal mechanism is concerned, they are still subject to derangement from two external causes—(1) failure of current, and (2) interruption in, or rupture of, the communicating wire. In either case the clocks would stop, which, in a large system, even if it seldom occurred, would, when it did occur, be serious. A clock that continues to go as an independent clock, even with some little error, appears to me to be preferable to one that from the causes mentioned may come to a stand, though Mr. Hope-Jones seems to think otherwise. It is for the reason mentioned that I rather cling to the principle either of continuous control, or of the synchronising at short intervals, of self-contained clocks, although there is, no doubt, the trouble of periodically winding such clocks. It is more or less a question of degree. If Mr. Hope-Jones can ensure uninterrupted wire communication and constancy of current, and if his step-by-step movement be as reliable as he appears to say, we may then congratulate him on having developed a system that may be of great benefit. But there must be no failures, or next to no failures. For it is when there is any possibility of such occurring that the superiority of the principle of control over that of driving comes in.

With reference to Mr. Hope-Jones' remark on the little progress made in the application of electricity for the promotion of more accurate timekeeping, I may mention, as a matter of history, that in

the year 1866 I accompanied a deputation from the British Horological Institute to a committee of the Court of Common Council of the City of London urging the establishment of public controlled clocks showing seconds, and placed near the leading thoroughfares, with dials a little above a man's head. Controlled on R. L. Jones' system from a central clock in the City brought daily to time, as is the central Greenwich clock, the plan was quite practicable; but nothing was done. The opposition to it was believed to come from those who might have been expected to approve of it. Mr. Ellis.

Mr. F. Hope-Jones, in reply, said: In reply to Mr. Lund I regret that I am unable to adopt his classification of electrical clocks under the headings Impelled, Controlled, and Synchronised. I thought it was good at the time he devised it, and I read it again with interest only a few weeks ago in his paper before your predecessors, the Society of Telegraph Engineers. In adopting the classification which I put in my paper I have only followed a very good lead, viz., those authors in France and Germany who have gone into this matter far more thoroughly even than I have. We have no standard works on the subject here in England, and must go abroad for them. Dr. Tobler, M. Kareis, and M. Favarger, of Neuchatel, do not ignore self-contained, self-wound clocks, and they consider that what Mr. Lund calls "controlling" is only a form of synchronisation. In that I agree with them. Mr. Lund made a very strong point of the battery, and that has also been touched upon by several speakers, Mr. Harrison among others. The question is not so serious, I believe, as has been made out. Mr. Lund spoke particularly of the fact that a contact in the case of synchronised or correcting methods was only required once an hour, whereas in the method I advocate it is required once every half-minute. I would point that although that is so, the demand we make upon the battery is absolutely less than that made by synchronisation. The reason is this: The amount of electrical energy required to move the hands (which are necessarily mounted spring-tight upon their arbors) is considerable, and a contact of at least one second duration is required for the purpose. But with the light aluminium balanced hands used in our clocks we require a contact of less than $\frac{1}{110}$ second duration. Consequently even if the amount of electrical energy were the same in each case, we use less than is required in the synchronising method. As a matter of fact we use a great deal less, because less energy is required at each stroke. Mr Hope-Jones.

In reply to Mr. Raworth, I have myself experienced the annoying "click" of the d ls in the Gare de Lazare Grand Terminus Hotel in Paris, and eventually I had to do as he did,—get up and turn off the switch. Could there be anything more ridiculous than a time circuit in which a switch is provided, to enable you to turn one of the dials off? It is infinitely better to have a key-wound clock than one which requires attention irregularly and not at stated periods. Silence has been spoken of by some of my supporters, and some whom I did not expect would speak for me. I thank them for replying in advance to many points which have been raised. The silence of the dial in the glass shade on the table has been obtained

Mr. Hope-Jones. mainly by insulating the movement itself (which must necessarily emit a slight click) from anything in the nature of a sound-board by suspending it from spiral springs instead of supporting it in rigid connection with the case. The result is that although the click is still there, it is not communicated to any sound-board and therefore is not heard. It is not a difficult matter to silence clocks. I think I may safely say that had the gentleman in the Post Office, who was referred to by Mr. Lund and Mr. Stockall, been provided with one of these clocks which has a very light movement, made of thin metal, cemented on to the back of the dial by rubber pads, and consequently mainly insulated from the dial which would otherwise act as a sound-board, he would not have complained. This clock is so quiet that it does not cause annoyance in any ordinary room, although I admit it is not good enough for a bedroom. The one with the movement supported by spiral springs is suitable for this purpose and cannot be heard when lying awake at night.

In reply to Professor Ayrton's question, I would point out that in the pendulum movement exhibited there is a maintaining spring which perhaps has not been noticed. The click which supports the weighted lever communicates its thrust to a ratchet disc, but the ratchet disc is not in rigid connection with the wheel. On the contrary, it is loose upon its arbor and is connected with the wheel through the medium of a spring. There is also a back-stop click engaging the wheel which comes into operation just before the winding action takes place. The result is that the going pressure is never off the escapement. Even at that minute instant of time when the action is taking place, when the weight is being lifted up, there is no diminution of the pressure upon the escape wheel.

Mr. Stockall referred to the absence of lock on one of the dial clock movements. He has, however, merely mistaken an interior pattern dial for a turret clock. The lock in this case is amply sufficient for light aluminium hands protected by a sheet of glass. In turret clocks, where the hands are exposed to the weather, they would be locked not only in the position of rest, but at every point in the cycle of operations.

With regard to the slight irregularity of the time circuit at the Institution of Mechanical Engineers mentioned by Mr. Worthington, the principal source of the trouble was the flooding of a conduit box which caused the main fuse to blow and cut off their supply, consequently stopping the clocks too. An earth developed on our clock wiring about that time also. The only other unsatisfactory point that I am aware of in that installation was the use of a large mirror as a dial ; this clock had to be taken out on account of the noise it made, being rigidly attached to the mirror.

In reply to Mr. Harrison, I admit that to use overhead lines extensively and indiscriminately for public time-service would be to court failure, but a very large number of dials would be served by comparatively few and short lengths which would be duplicated for safety. It would be easy to shut down any section of the time-service in business districts for testing and repairs for twelve hours between, say, 8 or 9 p.m. and 8 or 9 a.m. After installing nearly a thousand of these propelled

dials, and in view of the extensive use of more complicated systems on the Continent, I cannot agree with his pessimistic view of the commercial prospects of time-service. I admit that "10s. 6d. per annum is the interest on a very good clock indeed," but at present this half-guinea is absorbed in its weekly winding, regulation, and setting it to time, to say nothing of its repairs. Mr. Hope-Jones.

In conclusion, I would express my thanks to Mr. Harrison for dealing with the question of distribution. I could wish that more of the discussion had been devoted to it, for if there are any difficulties still to be encountered they will be met with here.

The PRESIDENT: It is now our pleasing duty to return thanks to Mr. Hope-Jones for his paper which has given rise to this most interesting discussion. I think those numerous gentlemen who have come here, not being members of the Institution, and have taken such an interesting part in this debate, should also be included in the vote. Will you give your thanks to Mr. Hope-Jones and to those gentlemen who have taken part in the debate? The President.

The vote was carried by acclamation.

The PRESIDENT: May I add, as a contribution to the discussion, that now for more than a year I have had some of Mr. Hope-Jones' clocks in the Technical College at Finsbury, two dials in the lecture theatres, two dials in other parts, the controlling clock being in my own private room, and I have not yet been sent to the mad-house by the noise of the master-clock. Until we had good batteries we had trouble with those clocks, but since we had good batteries, which is just a year ago, the trouble has ceased, and we have not had one dial different from another by a fraction. The clocks have kept absolute synchronism all through. I have ordered two more dials for our chemical laboratory, because we could not possibly have any other kind of clock there than one which could be hermetically sealed up so that the fumes should not get to the works inside.

The PRESIDENT announced that the Scrutineers reported the following candidates to have been duly elected:—

Member:

Alexander Russell, M.A.

Associate Members:

Leonard Fell Christy.
Montague George Alfred Humphrey-Moore.
Edgar Leslie Thorp.
Arthur Pemberton Wood.

Associates:

James Cormick.
Archibald John Walkom.

Student:

Alec. Cotching.

ORIGINAL COMMUNICATION.

HOW CONDENSER AND CHOKING-COIL CURRENTS VARY WITH THE SHAPE OF THE WAVE OF THE APPLIED E.M.F.

By ALEXANDER RUSSELL, M.A., Member.

Electrical engineers are aware that variations in the shape of the wave of the applied E.M.F. have a considerable effect on the working of certain alternating current apparatus. The currents produced, the hysteresis loss and the stress on the insulation of the windings all vary largely with the shape of the wave, and no test of transformers, arc-lamps, motors, etc., is at all satisfactory that leaves this out of account.

The experimental investigations made by Messrs. Beeton, Taylor, and Mark Barr, the results of which are printed in the 25th volume of this journal, p. 474, are conclusive on this point.

They proved amongst other results that the no-load current on a transformer was a maximum for the sine wave. It will therefore be interesting to investigate mathematically how the choking-coil and condenser currents vary with the shape of the wave. Owing to the infinity of shapes to be considered, it has only been possible to discuss a few families of curves. A study of these is instructive, as it shows clearly how very little information about the shape of the wave is given by a knowledge of the choking-coil and condenser currents. It also shows the necessity of revising the ordinary definition of form-factor.

In what follows, certain families of curves each individual member of which gives the same effective E.M.F. have been considered, and expressions have been found for the effective currents these would produce if applied to a condenser. In two cases also expressions have been found for the currents they would produce if applied to a choking coil. It will be seen that there is generally a particular member of the family that produces the minimum current when applied to a condenser, and another member that produces the maximum current when applied to a choking coil.

By an extension of Euclid's theorem that triangles on the same base and between the same parallels have the same area to curves between the same parallels which are given by a certain equation, unsymmetrical waves have also been considered.

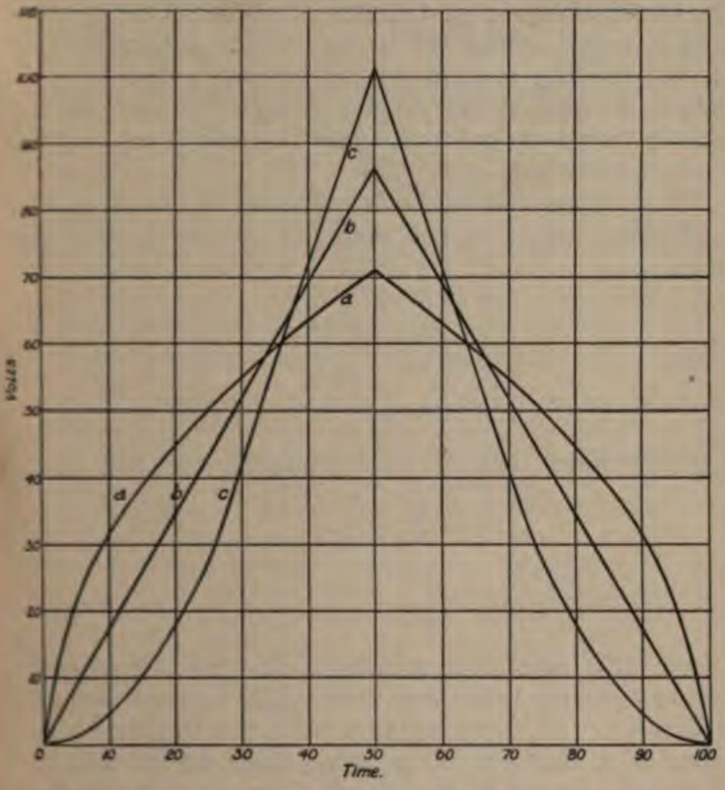

FIG. 1.—Equivolt Curves. The effective Voltage of each Curve is 50.

The curves obtained by giving particular values to n in the following equations would each produce a given effective voltage V.

$$\left.\begin{aligned} e &= V\left(\frac{4}{T}\right)^n \sqrt{2n+1}\; t^n & \text{from } t = o \text{ to } \frac{T}{4} \\ e &= V\left(\frac{4}{T}\right)^n \sqrt{2n+1}\left(\frac{T}{2} - t\right)^n & \text{from } t = \frac{T}{4} \text{ to } \frac{T}{2} \end{aligned}\right\} \quad . \; . \; (1)$$

In these equations e is the instantaneous value of the

E.M.F., t the time in seconds, T the period of the alternating current, and n a variable. The equations (1) give the positive half of the wave. By giving a numerical value to n we obtain the equation to a particular member of the family.

In Fig. 1 three of the curves are drawn, namely, those corresponding to n equal to $\frac{1}{2}$, 1 and 2. If n equals zero, we would of course get a rectangle. When n lies between o and 1 we get curves similar to "a," Fig. 1, namely, two curves meeting at an angle and concave to the axis of T. When n equals 1 we get the triangle "b," and when n is greater than 1 we get two curves meeting at an angle and convex to the axis of T.

If E denote the maximum value of e, v_m its mean value, and $\bar{v}$ the height of the centre of gravity of the curve, then—

$$E = V\sqrt{2n+1}$$

$$v_m = V\frac{\sqrt{2n+1}}{n+1}$$

$$V^2 = 2\,v_m\,\bar{v} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (2)^{[1]}$$

Now the form factor "f" is generally defined by the equation

$$f = \frac{V}{v_m}$$

$$\text{It is therefore } = \frac{2\,\bar{v}}{V}$$

From this definition it follows that the "form-factor" varies inversely as the area of the E.M.F. wave and as the frequency. As the maximum induction produced in the core of a choking coil is proportional to the area of the wave of the applied E.M.F., it follows that this maximum induction is inversely proportional to the "form-factor." Hence if two curves produce the same effective E.M.F. and have the same "form-factor," they will produce the same maximum induction in the core of a transformer, for example, and by Steinmetz's law the hysteresis loss will be the same in the two cases. The "form-factor," however, tells us nothing at all about the form of the curve. Two curves may have the same "form-factor," but their shapes

[1] See *The Electrician*, vol. xxxv., p. 115, "Graphical Methods of Finding Mean Square Values."

[redacted]

and their maximum heights may be quite different. Since also $\frac{V}{v_m} = \frac{2}{V}\bar{v}$ we see that all that it tells us in practice is the height of the centre of gravity of the wave.

In order to calculate the electrical effects produced by a wave of given effective E.M.F., it is necessary to know

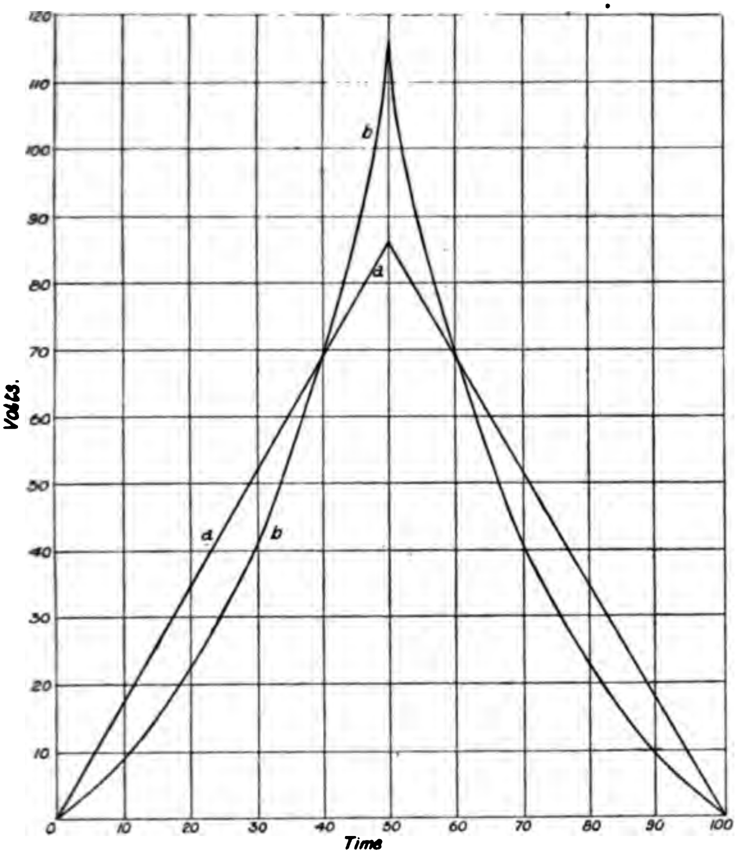

FIG. 2.—Equivolt Curves.

(1) The area of the wave.
(2) Whether it has more than one peak.
(3) The maximum height.
(4) Whether the curve is symmetrical.
(5) If unsymmetrical, in which quarter period it attains its maximum *value*.

The "form-factor" gives us information only about the first of these.

Suppose now that the wave given by equation (1) was applied to a condenser of capacity K farads. Then the current is given by the equations

$$i = \mathrm{V\,K}\left(\frac{4}{\mathrm{T}}\right)^{n} \sqrt{2\,n + 1}\,.\,n\,t^{n-1} \text{ from } o \text{ to } \frac{\mathrm{T}}{4}$$

etc. And if A be the effective value of the current (n greater than $\frac{1}{2}$)

$$\mathrm{A} = 4\,n\sqrt{\frac{2\,n + 1}{2\,n - 1}}\,\mathrm{V\,K}\,f,$$

where f is the frequency. As n increases from $\frac{1}{2}$, A diminishes until

$$n = \frac{\sqrt{5} + 1}{4} = 0{\cdot}809\,;$$

it then begins to increase again, and goes on increasing as n increases to infinity.

The minimum value of the condenser current that this type of wave produces is 6·661 V Kf, whilst a sine wave produces only 6·283 V Kf amperes.

If the wave given by equation (1) be applied to a choking coil whose self-inductance is L, then the current is given by

$$\left.\begin{aligned} i &= \frac{\mathrm{V}}{\mathrm{L}}\left(\frac{4}{\mathrm{T}}\right)^{n}\frac{\sqrt{2\,n + 1}}{n + 1}\left\{t^{n+1} - \left(\frac{\mathrm{T}}{4}\right)^{n+1}\right\} && \text{from } t = o \text{ to } \frac{\mathrm{T}}{4} \\ i &= \frac{\mathrm{V}}{\mathrm{L}}\left(\frac{4}{\mathrm{T}}\right)^{n}\frac{\sqrt{2\,n + 1}}{n + 1}\left\{\left(\frac{\mathrm{T}}{4}\right)^{n+1} - \left(\frac{\mathrm{T}}{2} - t\right)^{n+1}\right\} && \text{from } t = \frac{\mathrm{T}}{4} \text{ to } \frac{\mathrm{T}}{2} \end{aligned}\right\}$$

$$\text{Hence } \mathrm{A} = \left\{\frac{2\,(2\,n + 1)}{(n + 2)\,(2\,n + 3)}\right\}^{\frac{1}{2}}\frac{\mathrm{V}}{4\,f\,\mathrm{L}}.$$

As n increases from zero, A increases until it attains its maximum value, for $n = \dfrac{\sqrt{6} - 1}{2} = 0{\cdot}7245$, it then diminishes for greater values of n.

The maximum value of $\mathrm{A} = 0{\cdot}1589\,\dfrac{\mathrm{V}}{f\,\mathrm{L}}$ and $\mathrm{E} = 1{\cdot}565\,\mathrm{V}$

And for a sine curve $\mathrm{A} = 0{\cdot}1591\,\dfrac{\mathrm{V}}{f\,\mathrm{L}}$ and $\mathrm{E} = 1{\cdot}414\,\mathrm{V}$

[redacted]

The family of hyperbolic sine curves.

The equation to this family is

$$\left.\begin{aligned} e &= \mathrm{B} \sinh n \frac{t}{\mathrm{T}} && \text{from } t = 0 \text{ to } \frac{\mathrm{T}}{4} \\ e &= \mathrm{B} \sinh n \left(\tfrac{1}{2} - \frac{t}{\mathrm{T}}\right) && \text{from } t = \frac{\mathrm{T}}{4} \text{ to } \frac{\mathrm{T}}{2} \end{aligned}\right\} \quad . \quad . \quad . \quad (1)$$

Where $\mathrm{B} = \mathrm{V} \sqrt{\dfrac{n}{\sinh \frac{n}{2} - \frac{n}{2}}}$

When n is zero, the equations (1) become

$$\left.\begin{aligned} e &= \frac{4\sqrt{3}\,\mathrm{V}\,t}{\mathrm{T}} && \text{from } t = 0 \text{ to } \frac{\mathrm{T}}{4} \\ &= 4\sqrt{3}\,\mathrm{V}\left(\tfrac{1}{2} - \frac{t}{\mathrm{T}}\right) && \text{from } t = \frac{\mathrm{T}}{4} \text{ to } \frac{\mathrm{T}}{2} \end{aligned}\right\}$$

This is the triangle (*a*) shown in Fig. 2. The curve (*b*) in this figure is for $n = 10$.

It can be shown from (1) that

$$\mathrm{E} = \mathrm{V} \sqrt{\frac{n \cosh \frac{n}{2} - n}{2 \sinh \frac{n}{2} - n}}$$

$$v_m = \frac{4\mathrm{B}}{n}\left[\cosh \frac{n}{4} - 1\right]$$

For a condenser

$$i = \frac{\mathrm{K}\,\mathrm{B}\,n}{\mathrm{T}} \cosh n \frac{t}{\mathrm{T}}, \text{ etc.}$$

$$\text{Hence } \mathrm{A} = n\,\mathrm{V}\,\mathrm{K} f \left\{ \frac{\sinh \frac{n}{2} + \frac{n}{2}}{\sinh \frac{n}{2} - \frac{n}{2}} \right\}^{\frac{1}{2}}$$

$$= 4\sqrt{3} f\,\mathrm{V}\,\mathrm{K} \;(n = 0).$$

For a choking coil

$$A = \frac{V}{f\,L}\left\{\frac{2\,n - 6\sinh\frac{n}{2} + n\cosh\frac{n}{2}}{n^2\left(2\sinh\frac{n}{2} - n\right)}\right\}^{\frac{1}{2}}$$

$$= \frac{V}{f\,L\,\sqrt{40}} \quad \text{when } n = 0.$$

Family of curves including a rectangle, an ellipse and a parabola.

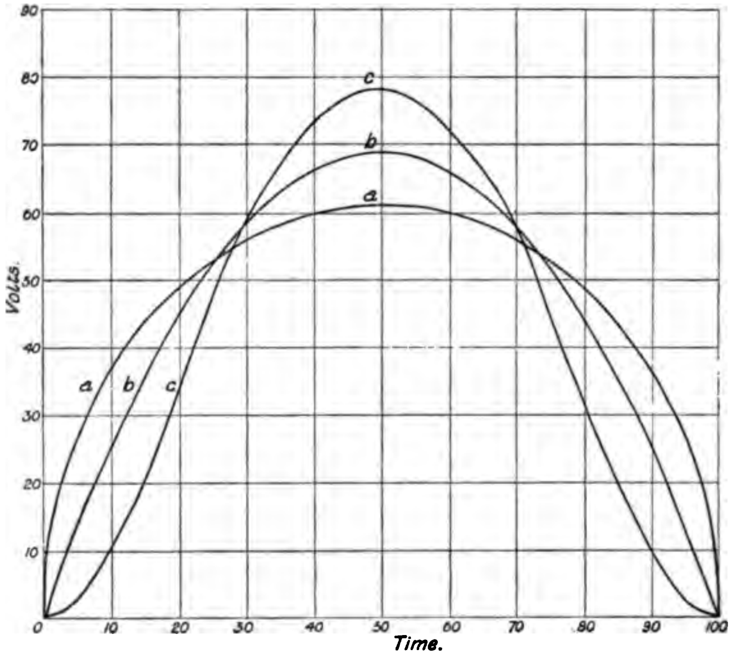

FIG. 3.—Equivolt Curves. (*a*) Ellipse. (*b*) Parabola.

The equation to this family is

$$e = B\left\{t\left(\frac{T}{2} - t\right)\right\}^{n} \text{ from } t = 0 \text{ } to \text{ } \frac{T}{2}$$

$$\text{Where } B = \left(\frac{2}{T}\right)^{2n} V\,\frac{\sqrt{\Gamma(4\,n + 2)}}{\Gamma(2\,n + 1)}$$

$$\textit{Also } E = \frac{V}{4^{n}}\,\frac{\sqrt{\Gamma(4\,n + 2)}}{\Gamma(2\,n + 1)}$$

[redacted]

$$e_m = V \frac{\{\Gamma(n+1)\}^2}{\Gamma(2n+2)} \cdot \frac{\sqrt{\Gamma(4n+2)}}{\Gamma(2n+1)}\text{[1]}$$

The curves in Fig. 3 are (a) $n = \frac{1}{2}$, an ellipse (b) $n = 1$, a parabola and (c) $n = 2$, a biquadratic.

For a condenser, $i = n \, B \, K \, t^{n-1} \left(\frac{T}{2} - t\right)^{n-1} \left(\frac{T}{2} - 2t\right)$

$$\therefore \; A = 2\sqrt{\frac{2n(4n+1)}{2n-1}} \, f \, V \, K$$

Hence A is a minimum when $n = \frac{\sqrt{6}+2}{4} = 1 \cdot 112.$

In this case $A = 6 \cdot 293 \, f V K$; $E = 1 \cdot 397 \, V$.
For a sine curve $A = 6 \cdot 283 \, f V K$; $E = 1 \cdot 414 \, V$.

Family of sine curves.

The equation to the E.M.F. is

$$e = E \sin^n \frac{2\pi t}{T}$$

Where $E = \sqrt{\dfrac{\pi^{\frac{1}{2}} \, \Gamma(n+1)}{\Gamma\left(\frac{2n+1}{2}\right)}} \, V$

$$e_m = \frac{\Gamma\left(\frac{n+1}{2}\right)}{\Gamma\left(\frac{n+2}{2}\right)} \sqrt{\frac{\Gamma(n+1)}{\pi^{\frac{1}{2}} \, \Gamma\left(\frac{2n+1}{2}\right)}} \, V$$

When $n = 0$ we get a rectangle, $n = \frac{1}{2}$ we get the curve (a) in Fig. 4, when $n = 1$ the sine curve (b), and $n = 2$ the curve (c).

For a condenser we get for the effective value (A) of the current when n is greater than :

$$A = \frac{2\pi n}{\sqrt{2n-1}} \, f \, K \, V$$

This is a minimum when $n = 1$.

[1] Tables of log $\Gamma(n)$ are given in Williamson's "Integral Calculus."

It is important to notice that none of the E.M.F. curves considered generate as small a condenser current or as great a choking-coil current as the sine wave. It must, however, be noted that they are all symmetrical waves—that is, they all have their maximum values at the quarter period, and ordinates equidistant from the maximum ordinate are all equal.

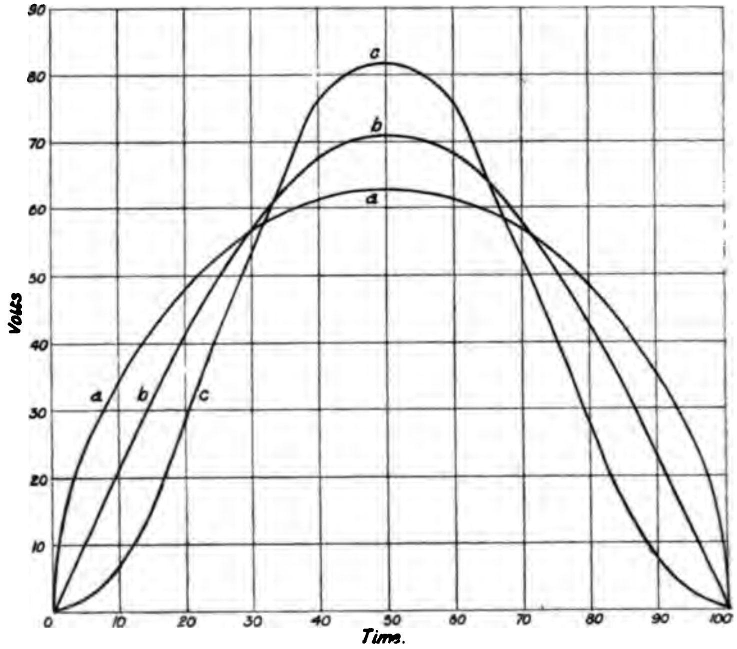

FIG. 4.—Equivolt Sine Curves.

To investigate what happens for unsymmetrical curves the following general theorem will be found useful :—

Theorem.

If $e = f(t)$ be the equation of a symmetrical wave of E.M.F, *i.e.* one in which $f(t) = f\left(\frac{T}{2} - t\right)$, then

[redacted]

$$\left.\begin{aligned} e &= f\left(\frac{T}{4}\cdot\frac{t}{\tau}\right) && \text{from } t = 0 \text{ to } \tau \\ e &= f\left(\frac{T}{4}\cdot\frac{\frac{T}{2}-t}{\frac{T}{2}-\tau}\right) && \text{from } t = \tau \text{ to } \frac{T}{2} \end{aligned}\right\} \quad \dots\dots \quad (1)$$

represents a distorted wave of E.M.F. which has the same maximum height, the same R.M.S. height, the same breadth, and the same area as the original wave.

This is easily proved. For example, if V be the R.M.S. of the e in (1), then

$$\frac{T}{2}\cdot V^2 = \int_0^{\tau}\left\{f\left(\frac{T}{4}\cdot\frac{t}{\tau}\right)\right\}^2 dt + \int_{\tau}^{\frac{T}{2}}\left\{f\left(\frac{T}{4}\cdot\frac{\frac{T}{2}-t}{\frac{T}{2}-\tau}\right)\right\}^2 dt$$

$$= \frac{4\tau}{T}\int_0^{\frac{T}{4}}\left\{f(t)\right\}^2 dt + \frac{4\left(\frac{T}{2}-\tau\right)}{T}\int_0^{\frac{T}{4}}\left\{f(t)\right\}^2 dt$$

$$= \int_0^{\frac{T}{2}}\left\{f(t)\right\} dt$$

Hence V is independent of the value of τ. Similarly we can prove that its area, etc., is the same as that of the curve $e = f(t)$. In Fig. 5 the middle curve shown in the sine curve and the others are distorted members of the same family $\left(\tau = \frac{T}{8} \text{ and } \frac{3T}{8}\right)$.

It follows that all the waves given by (1) when applied to a choking coil will each produce the same hysteresis and eddy current loss in the coil, and will each stress the insulation to the same amount. We will refer to the family of waves given by the equation (1) as waves of equal height.

It must be borne in mind, however, that there is an infinite number of families of waves of equal height. For example, (*a*) in Fig. 1 and the sine wave in Fig. 5 are the symmetrical members of two families of waves whose maximum heights are equal.

Of all E.M.F. waves of equal height applied to a condenser the symmetrical wave produces the smallest effective current.

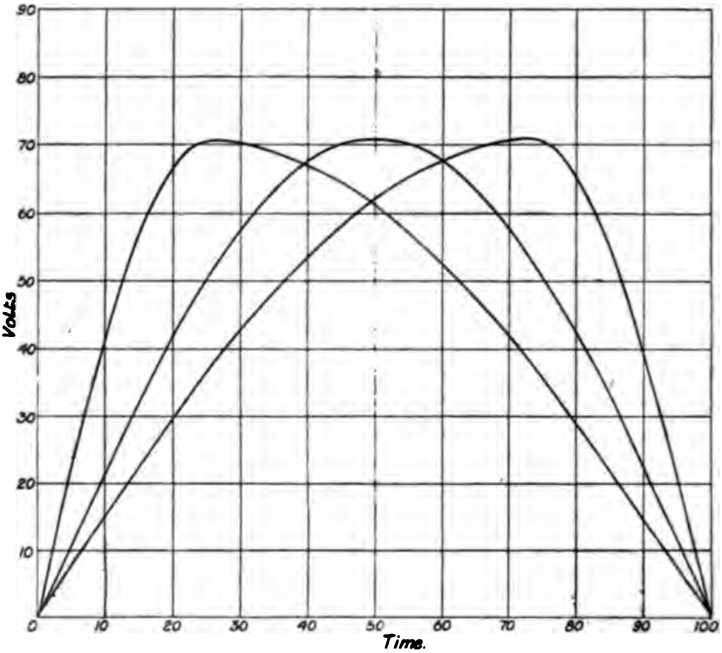

FIG. 5.—Equivolt Sine Curves of equal height.

If K be the capacity of the condenser, then the value of the current charging it is given by

$$i = \frac{T}{4\tau} K f'\left(\frac{T}{4} \cdot \frac{t}{\tau}\right) \text{ from } t = 0 \text{ to } \tau$$

$$= -\frac{T}{4\left(\frac{T}{2} - \tau\right)} K f'\left(\frac{T}{4} \cdot \frac{\frac{T}{2} - t}{\frac{T}{2} - \tau}\right) \text{ from } t = \tau \text{ to } \frac{T}{2}.$$

If A be the effective value of i, then

$$A^2 = \frac{K^2 \int_o^{\frac{T}{4}} \{f'(t)\}^2 \, d\,t}{4\tau\left(\frac{T}{2} - \tau\right)}$$

This is a minimum when $\tau\left(\frac{T}{2} - \tau\right)$ is a maximum, *i.e.*, when $\tau = \frac{T}{4}$. Hence the symmetrical wave produces the minimum effective current.

Of all E.M.F. waves of equal height applied to a choking-coil the symmetrical wave produces the greatest effective current.

Suppose that the resistance of the inductive coil is zero, and its self-inductance L,

$$\text{then } L\frac{d\,i}{d\,t} = f\left(\frac{T}{4} \cdot \frac{t}{\tau}\right) \qquad \text{from } t = \text{o to } \tau$$

$$\text{and } L\frac{d\,i}{d\,t} = f\left(\frac{T}{4} \cdot \frac{\frac{T}{2} - t}{\frac{T}{2} - \tau}\right) \text{ from } t = \tau \text{ to } \frac{T}{2}.$$

$$\text{Let } \int f(t)\,d\,t = \phi\,(t).$$

$$\text{Let also } \phi\,(\text{o}) = \text{o}.$$

Then we can show that the equation to the choking-coil current is

$$L\,i = -\phi\left(\frac{T}{4}\right) + \frac{4\tau}{T}\phi\left(\frac{T}{4} \cdot \frac{t}{\tau}\right) \qquad \text{o to } \tau$$

$$= \phi\left(\frac{T}{4}\right) - \frac{4\left(\frac{T}{2} - \tau\right)}{T}\phi\left(\frac{T}{4} \cdot \frac{\frac{T}{2} - t}{\frac{T}{2} - \tau}\right) \; \tau \text{ to } \frac{T}{2}$$

If A be the effective value of i, then

$$L^2A^2 = \left\{ \phi\left(\frac{T}{4}\right) \right\}^2 - \frac{64}{T^3}\left\{ X\tau^2 + Y\tau\left(\frac{T}{2} - \tau\right) + X\left(\frac{T}{2} - \tau\right)^2 \right\} . \quad (a)$$

$$\text{Where } X = \phi\left(\frac{T}{4}\right) \int_0^{\frac{T}{4}} \phi(t)\, dt - \int_0^{\frac{T}{4}} \left\{ \phi(t) \right\}^2 dt ;$$

$$\text{and } Y = \int_0^{\frac{T}{4}} \left\{ \phi(t) \right\}^2 dt.$$

It follows from (a) that A will be a maximum when $\tau = \frac{T}{4}$ if 2 X is greater than Y, *i.e.*, if

$$2\phi\left(\frac{T}{4}\right) \int_0^{\frac{T}{4}} \phi(t)\, dt \text{ is greater than } 3 \int_0^{\frac{T}{4}} \left\{ \phi(t) \right\}^2 dt.$$

Now it is known that [1]

$$\int_0^{\frac{T}{4}} \left\{ \phi(t) \right\}^2 dt = 2 \int_0^{\frac{T}{4}} \phi(t)\, dt \times \bar{y}$$

where $\bar{y}$ is the height of the centre of gravity of the curve $y = \phi(t)$.

Hence we have to show that $\frac{1}{3}\phi\left(\frac{T}{4}\right)$ is greater than $\bar{y}$.

Let O M N B (Fig. 6) be the curve $y = \phi(t)$. Then since $\frac{d}{dt}\phi(t) = f(t)$ and by hypothesis $f(t)$ increases as t increases,

[1] See *The Electrician*, vol. xxxv., p. 115.

therefore the slope of the curve O M N B increases with t. In the figure let $OT = \frac{T}{4}$, then B T is $\phi\left(\frac{T}{4}\right)$ and the height of the centre of gravity of the triangle B O T is $\frac{1}{3}\phi\left(\frac{T}{4}\right)$. Also dividing the figure B N M O into triangles having their

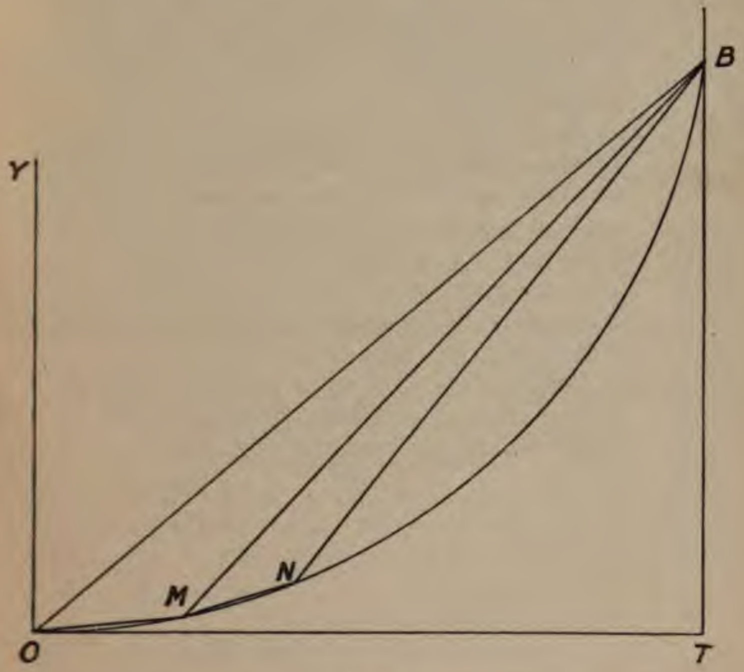

FIG. 6.

vertices at B, we see that the height of the centre of gravity of B N M O is greater than $\frac{1}{3}\phi\left(\frac{T}{4}\right)$ and therefore the height of the centre of gravity of the remaining part of the figure $(\bar{y})$ is less than $\frac{1}{3}\phi\left(\frac{T}{4}\right)$.

Hence $\frac{1}{3}\phi\left(\frac{T}{4}\right)$ is greater than $\bar{y}$, and therefore the magnetising current is a *maximum* for the symmetrical curve.

The preceding theorems seem to justify the following conclusions :—

1. A knowledge of the effective currents produced in a condenser and a choking coil by a given alternating E.M.F. gives us practically very little information about the shape of the wave.
2. The "form-factor" is not a suitable name for $\frac{V}{v_m}$. It would be better to call it the "area-factor" or the "hysteresis-factor" if it is really necessary to give this ratio a name.
3. The sine curve wave applied to a condenser produces a smaller effective current than any of the curves we have considered. If this current is not the smallest produced by any wave it must be something very nearly equal to the absolute minimum.
4. The sine curve wave applied to a choking coil produces a larger magnetising current than any of the waves we have considered.
5. In a family of waves of equal height the symmetrical wave produces the maximum choking-coil current and the minimum condenser current.

COMMUNICATION.

REPORT OF COMMITTEE ON COPPER CONDUCTORS.

THE advantages of standardising are being largely advocated for almost all classes of engineering products, but copper conductors have hitherto not been included in the list as every one has assumed that they were already standardised, and that Matthiessen had settled the resistance and temperature co-efficient of copper in his researches nearly forty years ago.

This assumption is far from being true, and the catalogues of various electrical cable makers, as published before 1899, show considerable discrepancies in the resistance and weight of nominally the same cables, while the Post Office issued a specification differing from all the others.

In order to remedy this confusion, a Committee was formed of those interested, to determine a standard, and the Institution of Electrical Engineers, the General Post Office, and the principal manufacturers of rubber-insulated cables sent representatives. Meetings were held early in 1899, and the report given below was adopted by the following delegates :—

Sir W. H. Preece, K.C.B., F.R.S., Chairman.
Mr. J. Gavey,
Mr. H. Hartnell,
For the General Post Office.

Prof. W. E. Ayrton, F.R.S.,
Mr. W. M. Mordey,
Mr. Herbert A. Taylor,
For the Institution of Electrical Engineers.

Mr. J. W. Conolly,
Conolly Bros., Ltd.
Mr. R. J. Hatton,
Henley's *Telegraph Works*, Ltd.

Mr. W. E. Gray,
I. R. G. P. and Telegraph Works, Ltd.
Mr. A. Paterson,
Johnson and Phillips.
Mr. F. Jacob,
Mr. J. S. Huddlestone,
Siemens Bros., Ltd.
Mr. A. H. Howard,
W. T. Glover and Co., Ltd.

The Telegraph Manufacturing Company, Ltd., and the London Electric Wire Company, Ltd., also co-operated in forming the Committee, and have adopted its recommendation.

The Report of the Committee is as follows:—

1st. RESOLVED that Matthiessen's standard of ·153858 standard ohms resistance for a wire one metre long weighing one gramme at 60° Fahr. be taken as the standard for hard-drawn high conductivity commercial copper.

2nd. Hard-drawn copper to be defined as that which will not elongate more than 1 per cent. without fracture.

3rd. RESOLVED that Matthiessen's standard of ·150822 standard ohms resistance for a wire one metre long weighing one gramme at 60° F. be taken as the standard for annealed high conductivity commercial copper.

4th. Copper to be taken as weighing 555 lbs. per cubic foot at 60° F. which will give a specific gravity of 8·912.

5th. RESOLVED that Messrs. Clarke, Forde, and Taylor's temperature co-efficient as published in their pamphlet dated February 20, 1899, be adopted, and that the average co-efficient of 0·00238 per degree Fahrenheit be adopted for commercial purposes.

6th. RESOLVED that the resistance and weight of conductors be calculated from the actual length of the wires.

7th. RESOLVED that a lay of twenty times the pitch diameter be taken as the standard for the calculation of tables.

8th. RESOLVED that 2 per cent. variation of resistance or weight be allowed in all conductors.

9th. RESOLVED that an allowance of 1 per cent. increased

resistance, as calculated from the diameter, be allowed on all tinned copper between Nos. 22 and 12 gauges inclusive.

Note to 1st and 3rd.

The figures inserted have been calculated for 60° F. from the figures 0·1469 per metre gramme for hard-drawn and 0·1440 for annealed at 32° F. by Matthiessen's formula.

$$R\,t^{\circ} = \frac{R\,32^{\circ}}{1 - 0{\cdot}00215006\,(t-32) + 0{\cdot}00000278\,(t-32)^2}$$

A. H. HOWARD,
Honorary Secretary.

From the above data the following formulæ are obtained :—

SOLID WIRES.

Copper weighs 555 lbs. per cubic foot at 60° F. Specific gravity = 8·912.

The resistance of annealed high conductivity commercial copper is :—

Resistance per cubic inch 0·00000066788 standard ohms.
Resistance per cubic cm. 0·00000169639 " "
Resistance of 100 inches weighing 100 grains . 0·150158 " "

$$\text{Resistance per mile} = \frac{0{\cdot}042317}{\text{Area in square inches.}} \text{ " "}$$

$$\text{Resistance per yard} = \frac{0{\cdot}000024044}{\text{Area in square inches.}} \text{ " "}$$

Resistance per mil. foot = 10·2044 standard ohms.

The resistance of hard-drawn high conductivity commercial copper is :—

Resistance per cubic inch = 0·000000681327 standard ohms.
Resistance per cubic cm. = 0·00000173054 " "
Resistance of 100 inches weighing 100 grains = 0·153181 " "

$$\text{Resistance per mile} = \frac{0{\cdot}0431689}{\text{Area in square miles.}} \text{ " "}$$

$$\text{Resistance per yard} = \frac{0{\cdot}0000245277}{\text{Area in square inches.}} \text{ " "}$$

Resistance per mil. foot = 10·4099 standard ohms.
Weight per mile in lbs. = 20,350 × area in square inches.
Weight per yard in lbs. = 11·5625 × area in square inches.

Cables.

A lay of twenty times the pitch diameter is adopted as a standard, and the resistance in parallel of the wire is taken as the resistance of the cable.

Resistance of three-strand cable = 0·33742 × resistance of each wire.

"	four	"	0·253065	"
"	seven	"	0·1443557	"
"	twelve	"	0·084355	"
"	nineteen	"	0·0532424	"
"	thirty-seven	"	0·0273493	"
"	sixty-one	"	0·0165911	"
"	ninety-one	"	0·0111222	"

Weight of three-strand cable = 3·03678 × weight of each wire.

"	four	"	4·04904	"
"	seven	"	7·07356	"
"	twelve	"	12·1471	"
"	nineteen	"	19·2207	"
"	thirty-seven	"	37·4414	"
"	sixty-one	"	61·7356	"
"	ninety-one	"	92·1034	"

The above formulæ give the standards, but a variation of 2 per cent. in resistance or weight is allowed for losses in manufacture.

These figures have been adopted by all of the parties represented, and it is hoped that they may become the universal standard for Great Britain.

The measurements made by Dr. Matthiessen were for the purpose of determining the best metal to use for a standard resistance, and the permanence of the resistance was of more importance than the actual numerical value.

The specific gravity of the copper was not taken, and as the results are given by length and weight they afford no means of determining the resistance of a wire of any given *diameter.* In addition B.A. units have been confounded

with standard ohms, so that discrepancies have arisen from both causes.

The resistance of a stranded conductor varies according to the lay of the wires. Some makers use a lay of twelve times the pitch diameter, while others go so high as thirty times the pitch diameter; twenty was adopted as an average figure, and the resistances calculated from the actual length of the wires, viz., 1·01226 times the length of the cable for all except the centre wire.

As the Post Office specifications will be issued in accordance with the above report, and as all of the manufacturers mentioned will include the same figures in their catalogues, there seems little doubt that these standards will be adopted throughout Great Britain.

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JOURNAL

OF THE

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Founded 1871. *Incorporated* 1883.

VOL. XXIX. 1900. No. 143.

VISIT TO SWITZERLAND.

REPORT OF THE MEETING HELD IN THE POLYTECHNIKUM AT ZÜRICH,

On Wednesday, September 6th, 1899,

Professor SILVANUS P. THOMPSON, President, in the Chair.

The President having announced that there was no formal business to be transacted,

Professor Gnehm, in the name of the Staff of the Polytechnikum, delivered a cordial address of welcome to the Members of the Institution.

The Secretary, in the absence of the author, then read the following paper :—

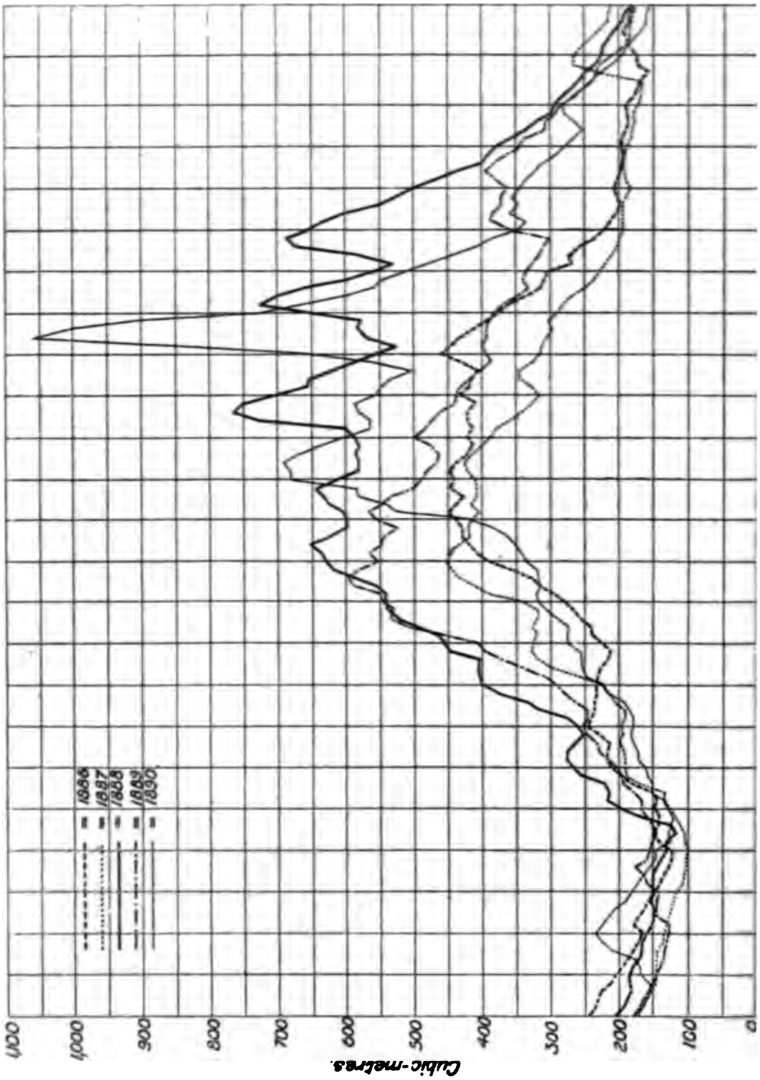
THE UTILISATION OF THE SCHAFFHAUSEN WATER POWER.

By ALFRED AMSLER, Ph.D.

The rapids of the Rhine at Schaffhausen were utilised long before the erection of the present works. A weir which is now for the most part demolished, then forced the water to the right bank of the river, where it drove a large number of undershot water-wheels. Most of these old-fashioned motors are still working—driving flower-mills, smithies, and the like.

In 1858, when the water of the Rhine fell to an extraordinarily low level, the idea of utilising the water power in a more efficient and more modern way occurred to certain enterprising citizens of Schaffhausen, and was in part realised during the years 1861–1865.

The Rhine at Schaffhausen was apparently a ver suitable river for the utilisation of water power. By cor structing a stowing dam across the river, and by excavatin



only a short canal in the bed of the river, it was possible t stow the water so as to realise a difference of levels of abo *four metres* without exposing the banks of the river t *inundation*. The quantity of water delivered by the Rhi

at Schaffhausen varies from 120 to 1,000 cubic metres per second. This variation may be considered slight as compared with other Swiss rivers, and even with the Rhine at

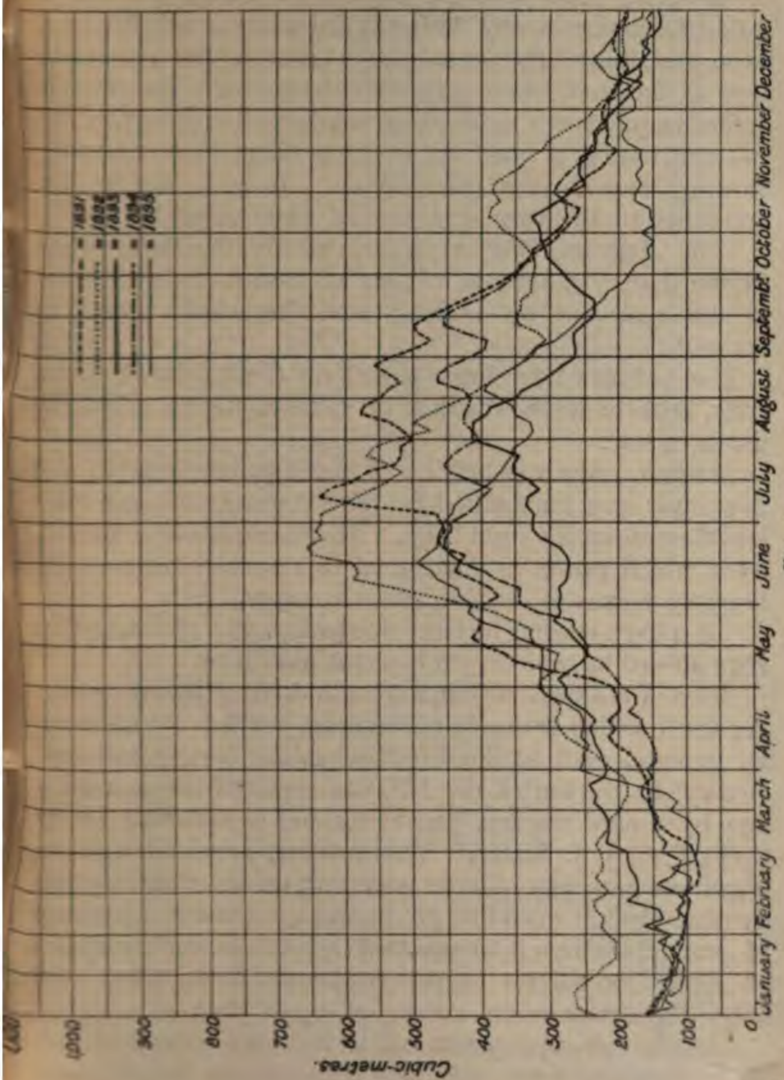


FIG. 2.

Rheinfelden. Diagrams (Figs. 1 and 2) show the rate of flow of water at Schaffhausen at different periods of the years 1885–1895.

It has already been stated that the waterworks were

built during the years 1861–1865. It must be remembered that at that time modern engineering was only at its beginning, and had not attained its present perfection.

No other plant of equal magnitude was in existence to guide the engineers who designed the works at Schaffhausen. Moreover, local difficulties—as, for example, the bad condition of the rock forming the river-bed, which has scarcely sufficient resistance to allow of anything being fastened to it—contributed a good deal to the delay in erecting the stowing dam across the Rhine. Indeed, during the construction, the dam was washed away several times.

The diagram (Fig. 3) shows clearly the construction of the dam. It consists of sets of stones each anchored to the river-bed by a chain, and the whole united by concrete.

The turbines have been placed on the left bank of the river, because there was then no suitable place available on the right side.

At first, only one turbine of 200 h.p. was erected, and the power was transmitted by wire ropes across the river and then along the right bank. Now there are four stations from which power is distributed to the workshops in the town by means of shafting and wire ropes.

In 1869 a second turbine of 250 h.p. was added, and in 1872 a third turbine of 300 h.p. was put down.

Two of the three turbines are still driving the wire ropes; the third, which formerly transmitted 300 h.p. by means of an inclined shaft to the Bindfadenfabrik (string and rope factory) on the top of the hill, was replaced some months ago by a new 350 h.p. Jonval turbine constructed by the Swiss firm, J. J. Rieter. This turbine, provided with an ingenious and very reliable governor, drives a three-phase dynamo electric machine, producing a current at a pressure of 400 volts, which is transmitted by a cable over a distance of about 200 metres to the Bindfadenfabrik, where the current operates seven motors of 35 to 50 h.p.

The old wire-rope system was in its time a first-rate means for transmitting power over long distances (at Schaffhausen about 600 metres), and deserved the admiration of the engineers visiting the works. In the course of more than thirty years of uninterrupted working, however, the moving parts have worn out. This has led to vibrations which in

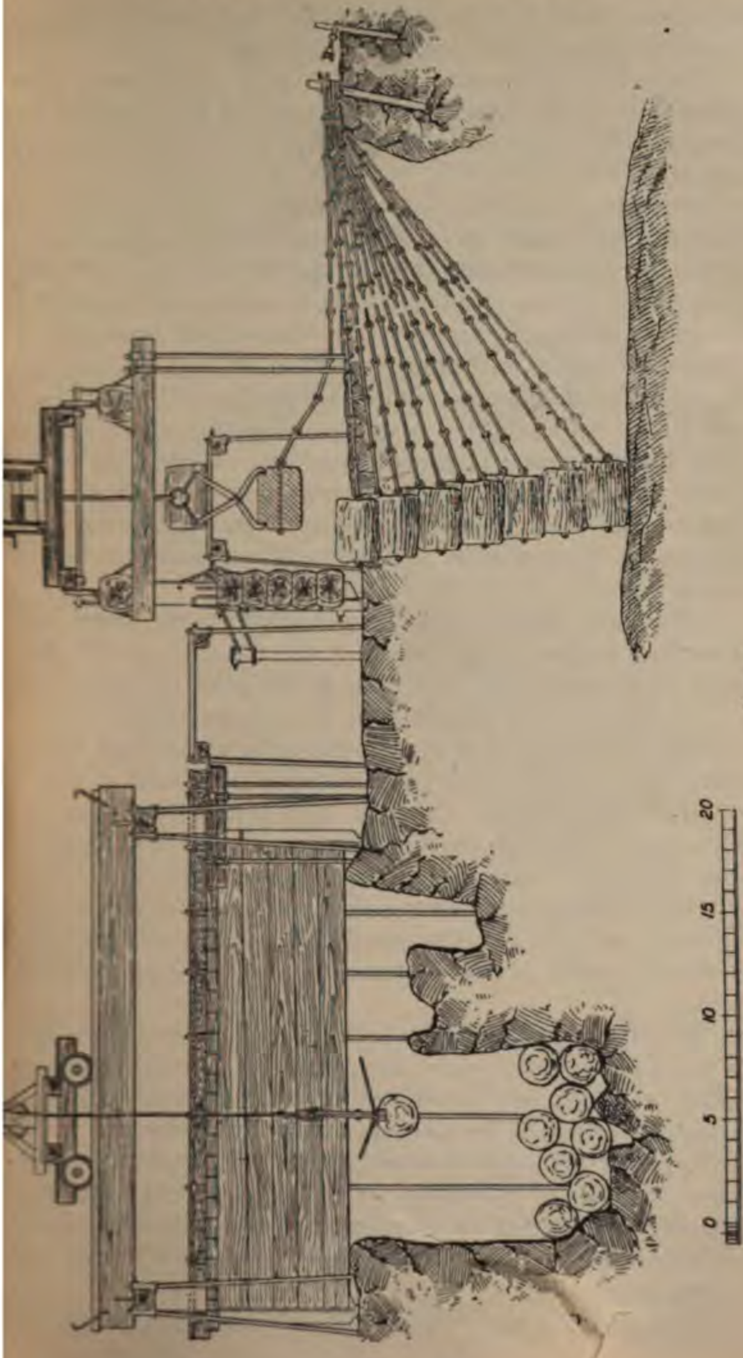


FIG. 3.

time have loosened the brackets in the stone pillars, so that the pulleys have become unsteady.

In order to prevent accidents and to secure a more steady run of the wire ropes, the speed of the turbines had successively to be reduced from 40 to 30 revolutions per minute.

The wear and tear of the ropes—30 millimetres in diameter, and made up of steel wires with a hempen core—is now very considerable, the average lifetime of a rope being only about eleven months, which is equivalent to a cost of about 52 francs a year per one transmitted horse-power. This expenditure, of course, swallows up a good deal (35 per cent.) of the income. This and the heavy loss of power due to the bad condition of the plant are the main reasons why the wire rope is to be given up. The whole of the water power realised will in future—that is to say towards the end of this year—be transmitted by electricity. The means of transmission will be a three-phase current at 2,000 volts.

The new motors will be Francis-turbines, fitted with movable guide blades (see Fig. 4). Such blades allow of a rapid and exact regulation of the inlet of water.

As the Rhine at Schaffhausen carries almost no silt, there is little probability that the movable blades will not have a long life. In silty water, the link motion would of course soon be destroyed. Each turbine will drive a 300 h.p. dynamo. The high-tension current will be distributed in the town by means of underground cables, and will be applied directly, without transformation, in the shops using upwards of 50 h.p. The smaller consumers will get transformed current of 200 volts. There will be no overhead wires.

The third turbine in the lower (new) house will also drive a 300 h.p. dynamo, producing a three-phase current at 2,000 volts. The current from this dynamo, now in course of construction, is to be combined with that supplied by the dynamo in the upper house. Next year an electric tramway will be in operation. The high-tension three-phas current is intended to drive motors coupled directly wit continuous-current dynamos supplying current at 550 vol to the tramways.

The users of high-tension current (2,000 volts) will ha

[redacted]

to pay 125 francs a year per brake horse-power measured at the motor. The users of low-tension current (200 volts) pay 150 francs per horse-power. Thus the users pay nothing for the losses of energy in the distributing cables and in the primary and secondary dynamos. These charges for mechanical energy supplied by a central station will be the lowest in Switzerland.

The electrical energy supplied to each motor will be measured by a counter, and the loss of energy in the motor

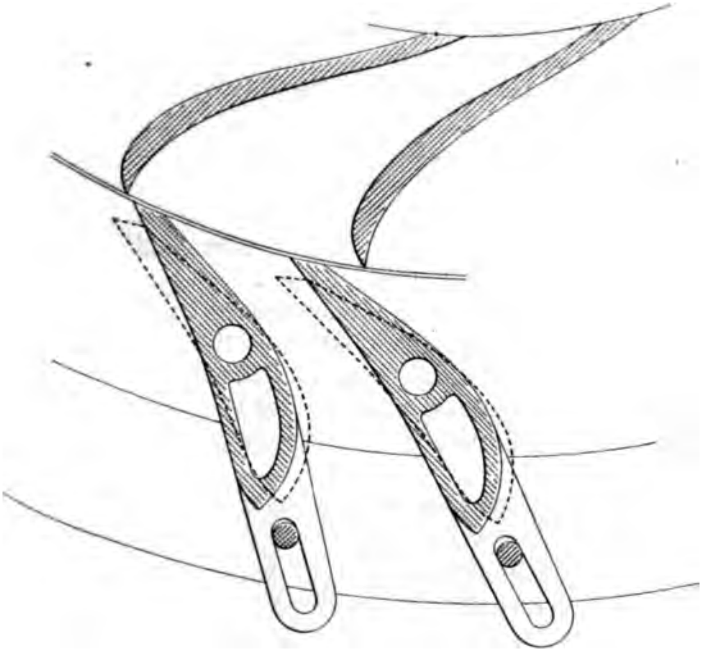


FIG. 4.

will be allowed for by assuming an efficiency of 80 per cent.

At present, that is to say as long as the wire ropes shall be in existence, the users of power are charged 100 to 150 francs per horse-power according to the quantity of power taken. The power used by the larger factories has been measured by means of recording dynamometers; or in cases in which the use of such an instrument was not practicable, the amount of horse-power was guessed.

In 1887 a *new set of five turbines* of 300 h.p. each has

been built. These turbines were originally arranged for driving dynamos by means of hempen ropes. Two turbines are still acting in this way; they drive continuous-current dynamos of 700 volts transmitting 600 h.p. to the Kammgarnspinnerei (a worsted spinning-mill) at a distance of about 500 metres. The current is transmitted by overhead copper-wire ropes to the factory, and there feeds a number of secondary dynamos placed in the different rooms. Two other turbines driving two single-phase alternate current dynamos of 300 h.p. are used for electric lighting. The high-tension current at 2,000 volts is distributed throughout the town and its environs to twenty-three transformers by underground cables. The transformed current of 120 volts is again distributed by underground cables. Overhead wires are admitted only beyond the limits of the town. At present about 7,000 incandescent lamps and 70 arc lamps are connected. The electrical energy is either measured by counters, or is only guessed, and is to be paid for at the rate of 6 centimes per hektowatt-hour.

The electric lighting plant, constructed by the Maschinenfabrik Oerlikon, is a great success; the light has never failed since it was started two and a half years ago.

The fifth turbine in the new house is, as already stated, being fitted with a three-phase dynamo intended for power transmission.

A prominent feature of the hydraulic plant is the superposition of two canals. The water leaving the three turbines in the upper (old) house flows through a canal underneath the visible canal, which latter leads the water into the five turbines in the lower (new) house. This curious arrangement was necessary so as not to interrupt the working of the old plant during the construction of the new one.

It will be noticed that there is no uniformity in the electric arrangements; there is a little of everything. The reason of this is that the different portions have been designed by different owners and at different epochs, according to what was considered the best at the time. It is well known that the progress in electrical engineering has run through many phases within the last ten years.

The water-power works were in the possession of a company till last year, when they were purchased by the

municipality of Schaffhausen, which already owned one-fourth of the shares.

It is not unlikely that, within a couple of years, the

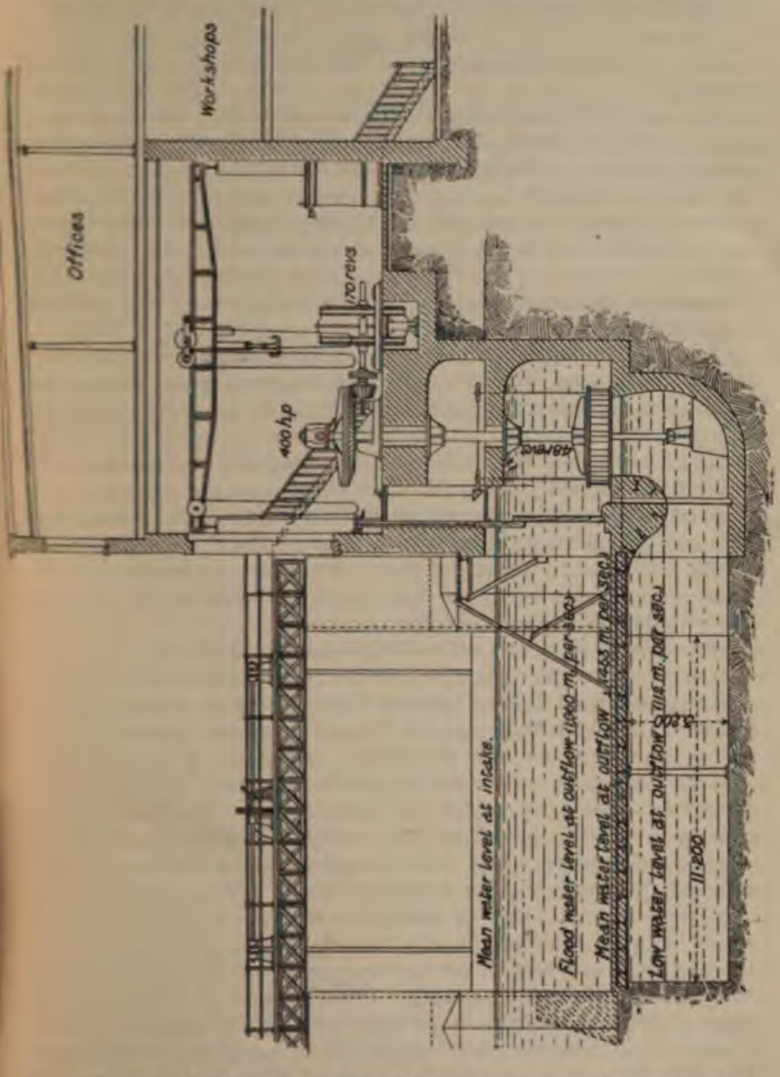


FIG. 5.

industry of Schaffhausen will have grown at such a rate that an extension of the power-station will again be necessary. Then the hydraulic part of the plant will no longer be sufficient, and a thorough reconstruction will no doubt be indispensable.

[illegible] passages and axial

[illegible] found that we may

[illegible] which are probably

[illegible] which is twice or more

times what [illegible] efficiency than from say 75

to 70 per cent., and in this way get a turbine for a given power and height of fall which has twice or more times the angular velocity of the turbine that seems best to the hydraulic engineer. Again, as high speeds of turbine are so very important in these low falls it is to be remembered that for any given class of turbine we get double the speed in a 100 h.p. turbine that we get in a 400 h.p. turbine with the same height of fall, and hence it may be very important to have more units of less power each. It does not seem to me, however, that high-speed machines of any kind are in great request in Switzerland whether driven by turbines or steam engines, and I have been often surprised to see the large size of exciters rendered necessary by the slow speed of the main machine. Professor Perry.

[*Added 16th October.*]—From Dr. Amsler's paper I find that the steel wire rope used now in power transmission at Schaffhausen has a life of only about eleven months, so that the loss of money due to wear and tear of the rope is more than £2 per horse-power per year, and this is 35 per cent. of the gross income. This is one of the most important pieces of information in Dr. Amsler's valuable paper. For many years every professor of engineering and all the authors of the best books on power transmission have vaunted this best and largest example of transmission by ropes, and now we are told that it is to disappear in favour of an electrical system of transmission of power to the mills of the town!

Professor F. PRÁŠIL explained the Construction and Action of the Transformer Turbine, dealing with the first experiments he had conducted in this field in April, 1899.[1] Prof. Prášil.

The investigations were undertaken with the object of finding means for driving dynamos at increased speed, directly by low-pressure turbines, without having recourse to a large number of rings, with the aid of energy transformations within the turbine. In the type adopted the energy available in one ring is not directly utilised, but is transferred to the water, passing through another ring of passages, which, therefore, may be said to work under an increased head and will be capable of yielding more power at higher speed. An additional turbine wheel is interposed between the guide passages and the turbine wheel proper. The principle is novel. Turbines with two wheels in series have indeed been proposed by J. Faulkner and by J. Hough, U.S. patents 99,548 and 190,028, of 1870 and 1877 respectively. The two wheels revolved in opposite directions, the one above the other, and the speeds of their concentric shafts were combined by suitable gearing. But it was not suggested to obtain higher speed by means of internal energy transformations. The system used is as follows:—A Jonval turbine has two concentric rings of guide passages, A_1 outside, and A_2 inside (see Fig. A). Underneath the guide rings is the so-called transformer wheel, with two rings of bucket passages, B_1, B_2; then

[1] Professor Prášil has since published a full account of his continued researches in the *Schweizerische Bauzeitung* xxxiv. Nos. 21, 22, 23, of Nov. 25, Dec. 2, 9, 1899, from which, at his request, the following abstract has been prepared.

Prášil. follows, again underneath, the turbine wheel proper, which the speaker calls the motor wheel, with one ring of passages C. A_1 discharges its water into B_1, A_2 into B_2, and B_2 into C. The blades and vanes of A_1 and B_1 are normally curved. The blades of A_2 are simply plane, perpendicular partitions, sending vertical jets of water into the passages of B_2. The curvature of the vanes of B_2 is such that the water enters the motor wheel C under pressure, but without shocks, as if direct from stationary guide ports. The transformer wheel is fixed on a hollow shaft surrounding the turbine shaft, and suspended by a collar bearing.

The efficiency of the system is determined in the following way :— If Q_1, Q_2 are the volumes of water in cubic metres per second supplied to the transformer wheel rings B_1 and B_2 respectively,

Ea_1, Ea_2 the available energies,
e_{a_1}, e_{a_2} the efficiency coefficients,
H the common head in metres,

then the total energy available

$$La = E_{a_1} + Ea_2 = \gamma H (Q_1 + Q_2),$$ where γ is the weight of a cubic metre of water $= 1{,}000$ kg.

The useful energy of the outer ring is e_{a_1} Ea_1, if we allow for friction, etc. This energy is not directly utilised, but transferred to the water passing through the inner passages B_2, whose useful energy will be

$$L'a = e_{a_1} Ea_1 + Ea_2 = e_{a_1} \gamma H (Q_1 + Q_2) = \gamma Q_2 H',$$

where H' is the increased head acting in B_2,

$$H' = \left(e_{a_1} . \frac{Q_1}{Q_2} + 1 \right) H'.$$

Introducing $\varepsilon_h = \frac{H'}{H}$ $\varepsilon_q = \frac{Q_1}{Q_2}$, then

$$\varepsilon_h = e_{a_1} \varepsilon_q + 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(I.)}$$

The head has been increased by transformation, hence the name "transformer wheel." The symbol ε_h designates the ratio of transformation.

Of the energy $L'a$ we can utilise

$$Le = e_{a_2} . L'a = e_{a_2} \left(e_{a_1} \gamma Q_1 H + \gamma Q_2 H \right);$$

hence the total efficiency

$$\eta = \frac{Le}{L'a} = e_{a_2} \cdot \frac{e_{a_1} \frac{Q_1}{Q_2} + 1}{\frac{Q_1}{Q_2} + 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(II.)}$$

and therefore the efficiency ratio

$$\varepsilon_\eta = \frac{\eta}{e_{a_2}} = \frac{e_{a_1} . \varepsilon_q + 1}{\varepsilon_q + 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(III.)}$$

From equations (I.) and (II.) sheaves of curves (variable parameter

e_{a_2}) are derived, from which it is seen that the transformer ratio ε_h depends much more upon ε_q than upon e_{a_1}, whilst the opposite applies for the efficiency ratio ε_η. Prof. Prášil

In order to determine the speed relations, the system is compared to an ordinary single-ring turbine, whose wheel is geometrically similar to the motor wheel C, and which is designed for a water supply of $(Q_1 + Q_2)$ cubic metres per second under the head H. If D′ is the mean diameter of the motor wheel C, and D that of the comparison wheel, then approximately

$$\frac{D}{D'} = \sqrt{\frac{Q_1 + Q_2}{Q_2}} = \sqrt{\varepsilon_q + 1}.$$

The ratio of the circumferential speeds u' and u likewise :

$$\frac{u'}{u} = \sqrt{\frac{H'}{H}} = \sqrt{\varepsilon_h}$$

hence the ratio of the number of turns per minute :

$$\varepsilon_n = \frac{n'}{n} = \sqrt{\varepsilon_h(\varepsilon_q + 1)} = \sqrt{(e_{a_1}\varepsilon_q + 1)(\varepsilon_q + 1)}$$

$$= (\varepsilon_q + 1)\sqrt{1 - \frac{\varepsilon_q}{\varepsilon_q + 1}(1 - e_{a_1})}, \text{ or approximately}$$

$$\varepsilon_n = (\varepsilon_q + 1) - \tfrac{1}{2}\varepsilon_q(1 - e_{a_1}) \quad . \quad . \quad . \quad . \quad . \qquad \text{(IV.}$$

Equation (IV.) leads to a similar group of curves (with the same parameter e_{a_1}) with the aid of which the speed may be determined. Assuming an efficiency coefficient $e_{a_1} = 0{\cdot}80$, the author finds :

	$\varepsilon_q = 0{\cdot}6$	1·0	1·4
	$\varepsilon_h = 1{\cdot}48$	1·80	2·12
	$\varepsilon_\eta = 0{\cdot}925$	0·900	0·883
	$\varepsilon_n = 1{\cdot}54$	1·9	2·26
and if further	$e_{a_2} = 0{\cdot}76$		
	$\eta = 0{\cdot}703$	0·684	0·671

Thus the transformation ratio and the speed may be varied by changing ε_q.

The third question is whether the momenta of the two rings of the transformer wheel are sufficiently stable to prevent speed fluctuations and to ensure a uniform water-feed to the motor wheel. This problem is answered by investigating, how the momenta of the circumferential forces vary with different speeds at uniform water-feed. The influences of shocks are neglected in this deduction, which is permissible, as the experiments prove. It results that small variations in ε_q and in the resistance do not materially affect the speed of the transformer wheel.

The experiments were made in the Ravensburg (Württemberg) branch establishment of Escher Wyss & Co. with a Jonval turbine, which

Prof. Prášil. the firm placed at the speaker's disposal. The alterations were designed for a water supply of 2 or 3 cubic metres under a head of 3m. and for $\epsilon_q = 1$, that is to say, equal water volumes for both rings of the transformer wheel. Assuming an efficiency $e_{a_2} = 0{\cdot}74$ for the inner ring, the following results could be expected: $\epsilon_h = 1{\cdot}7$ or $1{\cdot}8$, $\epsilon_\eta = 0{\cdot}88$, and total efficiency $\eta = 0{\cdot}65$.

It would appear from an examination of the table given above that with ϵ_q greater than 1, a higher transformer ratio, and with ϵ_q less than 1, a higher efficiency should result than with $\epsilon_q = 1$. Further investigations will settle these points.

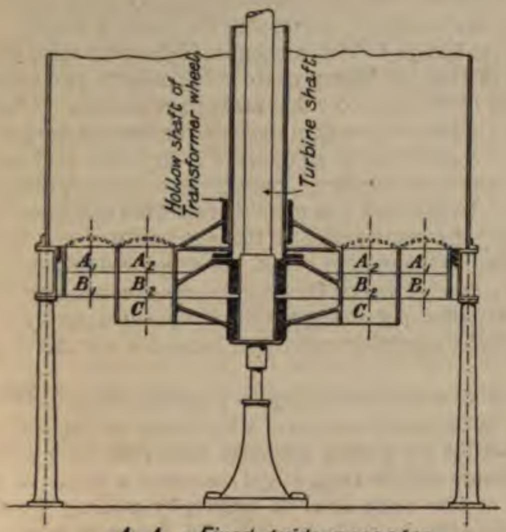
The suspension of the transformer wheel from a collar bearing which had to be undesirably large caused difficulties, and the bearing could not be placed high up, as there was hardly room for fixing a brake pulley on the transformer wheel shaft—in addition to the turbine shaft brake—under the ceiling. The bearing was hence at an unsuitably low level, and inaccessible during the trial runs. Some of the alterations had to be made under water. The outer guide ring A, has 30 blades, the inner A_2 12 vertical partitions; the outer transformer wheel ring has 30 vanes, the inner B_2 40; the motor wheel C is provided with 24 vanes. The blades and vanes of A, B, C are all of the normal type, with an inlet angle of almost 90°, soon passing into a strong slope; the vanes of B_2 were curved more symmetrically.

The numerous experiments[1] were not conducted under ideal conditions, but with great care. The water level was measured at six points, and the flow in seven or eight different sections of the shute, with the aid of Amsler hydrometers and of electric and other signals. Two chief lines of investigation were followed: 1. Brake tests at variable brake load without water measurements, in order to determine the relation between speed and power, and further to study any back reactions of the motor wheel; 2. Efficiency tests at constant brake load with water measurements. The admission was also varied. From the construction of the blades a maximum transformer-wheel speed of 70, and motor-wheel speed of 134 could be expected. The early experiments yielded speeds of 55 and 120, and a total efficiency of 53 per cent. only, but the uniformity of motion was satisfactory. When the admission to the outer ring B_1 was reduced, the speed of the transformer wheel went down; at an admission of 18/30 (inner ring full admission) the transformer wheel stopped, and on further reducing the admission to B_1, the transformer wheel began to reverse, making 12 revolutions when the outer passages B_1 were cut out completely. At that moment the motor wheel C gave 15·75 h.p. at 80 revolutions, its speed having diminished during the period of partial admission to the outer ring B_1. An increased water-flow through the inner vanes of B_2 also impaired the speed of the transformer wheel and the efficiency of the system. This was recognised to be connected with the water leakage through the clearance between the transformer and motor wheels, a point which was further studied theoretically and practically. The

[1] Tabulated in detail in the paper (loc. cit.).

clearance amounted to 5·5 mm.; when reduced to 2 mm., the speed and the power rose, the latter from 38·5 to 46 h.p. Prof. Prášil

As the unsatisfactory suspension of the transformer wheel and these various defects did not sufficiently account for the comparatively low values realised, the speaker finally, after a study of the velocity diagrams, altered the shapes of the blades in B_2 which proved too steep at the inlet. The total efficiency then rose to 62·3 per cent., the motor wheel developing 49·5 h.p. at 144 revolutions, although now a leakage became apparent through the clearance between the guide rings and the transformer wheel. This clearance was also 5·5 mm. and could not be reduced.



A_1, A_2 = Fixed guide-passages
B_1, B_2 = Transformer wheel.
C = Motor wheel.

FIG. A.

The following conclusions are drawn from the experiments:—

The transformer turbines would only be suited for low, variable heads and direct coupling. Their construction and erection would not offer any particular difficulties, apart from the transformer wheel suspension, nor involve high expense. Regulation by partial admission could be applied to the outer-ring passages of the transformer wheel, and the arrangement also be adapted to Francis turbines.

Mr. Uehlinger.

Mr. A. UEHLINGER: The old water-power works were completed about thirty-three years ago, and were regarded as quite an important enterprise at that time. The wire-rope transmission, conveying about 500 h.p. a distance of 700 metres was a great advance on previous practice, and it has found numberless imitators. After having been working during thirty-three years, in which time but very few of the many parts of construction have been renewed, there is no wonder that

Mr. Uehlinger.

this plant is in such a state that it would not serve much longer. For this reason, and in order to utilise the water power as fully as possible, a complete change in the system of power transmission, namely, from mechanical to electrical transmission, is being effected. This transformation was taken in hand about one year since and will be completed in the course of the year 1900.

Until now the consumers have been bound to the banks of the river Rhine, along which the wire ropes transmitted the power, but as soon as it is transmitted electrically by wires and cables there will be no limit in any direction. In consequence of the increased demand for power there will be not only an alteration, but an extension of the system. The power can be increased either by using a greater quantity of water or, preferably, by increasing the head of water.

During the two periods of maximum high-water level in this century the Rhine discharged about 1,100 cubic metres per second; at the lowest water level about 90 cubic metres per second. It, however, very seldom has a volume of less than 100 cubic metres per second. In designing water-power stations the engineer of to-day does not base his calculations on the *minimum* discharge, but only on a *moderate* discharge, at low-water level. In this way it is possible to get the efficiency considerably higher during the greater part of the year without any increased cost corresponding to the greater effect. During the short time of the lowest water level a good steam or Dawson gas reserve must be kept up. On examining the curves showing the discharges of water by the Rhine we find that at least 120 cubic metres per second are at the disposal of the work.

The head of water, amounting to 4 metres, obtained to the extent of three-fifths by means of a natural sill of rock in the bed of the river and of two-fifths by a solid artificial dam, built with great difficulty during the years 1863 to 1865, might be raised 1 metre at least during the period of low water-level in winter, by making the dam higher. We shall attain this by replacing the solid dam with a movable sluice-weir. It will allow of bringing the head of water up to at least 5 metres, which will afford 6,000 h.p. at low-water level, with the above-mentioned discharge of 120 cubic metres per second.

It must be mentioned that the conditions of the Rhine a[illegible] Schaffhausen and Neuhausen are very favourable to water-power ins[illegible]tallations, because the fall of the water is concentrated within very sh[illegible]rt sections along the river, so that we can dispense with canal works. [illegible] The quantity of water does not vary as much as in other rivers and we [illegible] have no wastefully high flood waters, as other Alpine rivers have perio[illegible]dically, because the Lake of Constance serves as a regulator. The w[illegible]ater, too, is absolutely as clear as crystal and thoroughly free from silt.

With little difficulty the falls of the Rhine at Ne[illegible]uhausen could be utilised for very high-water power by digging a [illegible] tunnel underneath the Schloss Lauffen to a power station, situated bel[illegible]ow the falls of the Rhine, discharging the water under a head of ful[illegible]ly 24 metres at the relatively small distance of not quite 400 metres. [illegible] This would render available about 28,000 h.p. at the lowest comp[illegible]tation. But for the present it is provided that no undertakings of [illegible] character may

carried out, and so one of the most charming falls in the world is protected from devastation. Mr. Uehlinger.

Mr. G. L. ADDENBROOKE: The installation at Schaffhausen and several other of those we have seen formed excellent examples of what could be done by means of overhead wires, and it has been pointed out that some of these wires have already lasted twelve years in an exceptionally trying situation. Seeing that wires of this character are practically prohibited in England, the opportunity seems to me a good one for raising the question as to how far this policy is a sound one, as it has already had, there is no doubt, a very deleterious effect on English enterprise. Mr. Addenbrooke.

Mr. L. BIRKS having moved the adjournment of the discussion, Mr. Birks.

On the motion of the PRESIDENT, a cordial vote of thanks to Dr. Amsler for his interesting paper, to Herr Ingenieur Uehlinger for the interesting diagrams that he had exhibited, and to Professor Prášil for his valuable contribution to the discussion on the same, was carried unanimously. The President.

Professor R. THRELFALL moved: "That the best thanks of the Institution of Electrical Engineers of London be, and hereby is, given to the Director and Teaching Staff of the Polytechnikum of Zürich for the use of their Aula for the purpose of this meeting, and for their great kindness in conducting the members of the Institution present in Switzerland over the admirable Laboratories of the College." Professor Threlfall.

The motion was seconded by Professor C. A. CARUS-WILSON, who reminded the members that several of the professors had returned to the Polytechnikum in the midst of the summer vacation especially for the purpose of accompanying the party through their several departments. Professor Carus-Wilson.

The motion, on being put to the meeting, was carried unanimously.

asking for subscriptions to help to equip the party of men from our Electrical Engineer Volunteer Corps that is to go to the Cape. I think this is a favourable opportunity of explaining better than I was able to do in my circular letter, both what is intended and what is the history of the movement up to the present time. The primary object that the corps had in view in placing a selected party of men and officers at the service of our Country, was that the Government should have at their disposal the services of a body of picked scientific men who combine science with practice, and who have sufficient familiarity with the modern developments of electrical engineering, together with the technical knowledge which they have acquired during the past two or three years in the use of war plant. The Government have accepted these services provisionally; that is to say, we are now waiting for instructions from Lord Roberts at the Cape, as to the nature of the plant with which we are to be equipped. I can tell you nothing further at present, even if it were desirable to do so, for the sources of information of the Pretoria journals reach very far.

In reply to certain questions put to me, I may say the Government no doubt will supply us with all the equipment that we require of a definite nature—engines, dynamos, projectors, cable, reels, telegraph apparatus and the like. But there is other apparatus and also comforts for our men which it is highly desirable we should have, and which cannot be provided out of the Government grant, and it is for these two purposes that it is intended to devote the very handsome subscriptions that we have already received. Up to the present, considerably over £800 has come in, and I reckon that the amount will reach £1,400 or £1,500, which is the sum I should like to see it reach. At this stage I w[illegible] not particularise, and will only say that nothing h[illegible] me more than the public spirit and generosity [illegible] our members. It has been perfectly extraordina[illegible] profoundly touched by it. We are not going [illegible] ing party. Those who go out are going mor[illegible] of saving or diminishing the vast waste of lif[illegible] going on in South Africa, by shielding, if [illegible] do so, our soldiers in passing through that [illegible] *fire that* they have had to traverse, in [illegible] *at night* that has hitherto been carrie[illegible]

and in such like operations. Our work will be of a humble nature, which will not be much thought of by the war correspondents, but I hope it will be none the less useful. I hope that the move we have made is a right one, for I am afraid that the fault so far has been that every one has trusted far more to English bull-dog pluck and tenacity and perseverance than to the undoubted good engineering and high scientific qualities that Englishmen, above all others, possess, when they are under fire and in difficult circumstances. I believe that we can show that, and that we can do some useful work for our country.

The PRESIDENT: The business before us now is the discussion of the Report of the Swiss Visit Committee on the visit of the Institution to Switzerland, in September, 1899, which has been duly printed and circulated, and which, by your leave, will be taken as read.

REPORT OF THE SWISS VISIT COMMITTEE ON THE VISIT OF THE INSTITUTION OF ELECTRICAL ENGINEERS TO SWITZERLAND IN SEPTEMBER, 1899.

The programme and itinerary of the visit were arranged by a committee
…pointed by the Council of the Institution on the 9th of March) consisting of
… J. W. Swan, F.R.S. (President), Professor W. E. Ayrton, Mr. H. Edmunds,
… A. Fleming, Mr. W. M. Mordey, Mr. R. P. Sellon, Mr. A. Siemens, Mr.
… Spagnoletti, and Professor Silvanus P. Thompson, F.R.S. (afterwards
…ent), acting in co-operation with Colonel P. E. Huber of Oerlikon, Mr.
… Brown of Baden, and Professor W. Wyssling of Zürich, who con-
…a Swiss Reception Committee, and to whose genial hospitality and
… devotion of time, energy, and knowledge the success of the meeting
…e most part due.
…ion of technical notes descriptive of the works visited was drawn
…or Wyssling for presentation to the members of the party, and
…reciated by them. This collection, with a few slight alterations,
…ional notes (compiled on the same method) concerning works
… not referred to in the original pamphlet, are here reprinted
…ncise account of the various installations in a form eminently
…nce. An index is given below.

…mbled at Basel on the morning of Saturday, September 2nd,
… Rheinfelden and Baden to Zürich, where they arrived the
… stayed until the following Wednesday. At Rheinfelden,
… power-station, the members were most hospitably enter-
…he Directors of the Kraftübertragungswerke, where they
… who had travelled *from Berlin* in order to be present.
…*he works of Messrs.* Brown, Boveri & Co. at Baden were
…*ürich.*

On the morning of Monday, September 4th, a visit was paid to the works of the Maschinenfabrik Oerlikon and to the generating stations of the Zürich-Oerlikon-Seebach electric tramway. In the afternoon a few of the members visited the works of Messrs. Sulzer Brothers and those of the Swiss Locomotive Factory at Winterthur; but the majority remained in Zürich to inspect the works of Messrs. Escher Wyss & Co., the municipal central station at Letten, and the transformer sub-station at Selnau.

On Tuesday, September 5th, the greater number of the party proceeded to Schaffhausen, visiting the old and new power-stations, the worsted mills, and the Falls of the Rhine, and calling at the works of Messrs. Sulzer Brothers on the return journey, whilst the remainder of the party were shown over the Landes Museum by the Director (Mr. H. Angst, who is also the British Consul-General), and over the silk-weaving works at Rüti on the Lake of Zürich. A few of those who took part in the excursion to Schaffhausen were able to visit the steel works of Herr Georg Fischer.

On the same evening the whole party enjoyed the princely hospitality of the Swiss Electro-Technical Society, and of the Maschinenfabrik Oerlikon, Messrs. Brown, Boveri & Co., and Messrs. Escher Wyss & Co., by whom they were entertained at a Banquet given in honour of the Institution in the Tonhalle at Zürich. It was to the great regret of all the guests that Colonel Huber was prevented by illness from attending, but a letter of welcome written by him was read by Mr. A. Hurter, the Secretary of the Maschinenfabrik Oerlikon, and his place in the chair was taken by Professor Wyssling.

The morning of Wednesday, September 6th, was devoted to a meeting, at which the President took the chair, in the Aula of the Polytechnikum in Zürich. At this meeting, after an address of welcome from Professor Dr. Gnehm, a paper by Dr. Alfred Amsler[1] on the *Utilisation of Water Power at Schaffhausen* was read; a discussion ensued, in which Mr. Gisbert Kapp, Mr. E. K. Scott, Professor J. Perry, Professor Prášil, Mr. Uehlinger, and Mr. Addenbrooke took part. On the motion of Mr. Birks, the discussion on the paper and on the various points of interest arising out of the visit to Switzerland was adjourned. A vote of thanks was unanimously accorded to Dr. Amsler for his paper, which it was agreed should be printed in the Journal. The meeting closed with a vote of thanks to the Director and Staff of the Polytechnikum for the use of the Aula for the meeting, and for their kindness in showing the party over the Polytechnikum, some of the Professors having returned to Zürich in the middle of the vacation especially for the purpose. This vote, on the motion of Professor Threlfall, seconded by Professor Carus-Wilson, was carried by acclamation.

The meeting was succeeded by a lunch given by the members of the party to their Swiss hosts, the President, Professor Silvanus Thompson, presiding. An opportunity was thus afforded to present to Dr. Max Huber, on behalf of his father, to Mr. C. E. L. Brown and to Dr. Wyssling, autograph albums containing the signatures of most of those present, together with portraits of Past Presidents of the Institution.

In the afternoon members were conducted over the diffe... of the Polytechnikum, and then proceeded to Luzern, where... for the night.

An early start was made on Tuesday, September 5th, th... by boat to Stansstad, and thence by the electric rail... viewing the power-house on the way; they then travell...

[1] See this volume, p. 175.

[redacted]

Pass to Interlaken, which became the headquarters for the remainder of the visit.

The Rathausen power-house at Lucerne was open for the inspection of members.

Friday, September 8th, was given up to a visit to the Jungfrau electric railway, the journey being made *viâ* Lauterbrunnen, where the power-station was inspected, and the Wengern Alp railway, to the Kleine Scheidegg, the starting point of the Jungfrau railway, and returned thence *viâ* Grindelwald to Interlaken. From the Kleine Scheidegg the party were conveyed over the Jungfrau Electric Railway, so far as it was then completed, namely to the Rothstock, about 9,500 feet above sea-level, and a distance of about two and a quarter miles from the Scheidegg station.

On Saturday, September 9th, members travelled to Thun by railway, calling at Spiez *en route* to view the Kanderwerk, in which is generated the power for the Burgdorf-Thun railway. After lunch in Thun the members assembled in the Kursaal, and votes of thanks to the President, proposed by Professor Threlfall and seconded by Mr. Trotter, and to the Secretary, proposed by Mr. Ferranti and seconded by Mr. Mordey, were carried unanimously. The afternoon was spent in examining the technical equipment of the Burgdorf-Thun railway. With this visit the official reunion in Switzerland ended.

INDEX TO ACCOUNTS OF WORKS AND INSTALLATIONS.

* [illegible] given in the order in which they were visited.

A.—FACTORIES IN THE ORDER IN WHICH THEY WERE VISITED.

1.—Works of the Alioth Electricity Company (*Elektricitäts Gesellschaft Alioth*), at Münchenstein, near Basel (and Lyons).

Founded 1881.

(Visited by some of the Party, Friday, September 1st.

Number of Workmen :—600.
Number of Staff :—120.
Departments of Works :—The Firm manufactures dynamos for direct and alternate- (one-, two-, and three-phase) current dynamos (from 30 to 1,200 HP.) ; motors ; transformers ; electrically driven cranes, tools, and fans ; switchboards and the various apparatus and fittings required in electric lighting. It also undertakes the design and construction of lighting and power installations, electric railways, electro-chemical installations and the like.

2.—The Electrical Works of Brown Boveri & Co., Baden (Swit-zerland) (and Frankfurt-am-Main).

Founded 1892.

(Visited Saturday, September 2nd.)

Number of Workmen :—1,300 at Baden and 350 at Frankfurt-am-[illegible]
Number of Staff :— 170 „ „ „ 40 „ „ „
Motive Power :—Water power from the Limmat (Central Stat[illegible]
Power distribution by two-phase alternating-current, with ab[illegible]
Floor space of the works about 26,000 square metres.
Area belonging to the works „ 80,000 „ „
The principal departments are exclusively engaged in bu[illegible] and alternating-current machinery, including gener[illegible] transformers, high-tension apparatus and switchboar[illegible]
Work produced :—

	since 1892		
	Number	HP.	KW.
Electric generators and motors	8,100	about 250,000	about
Transformers	4,700		100,000

Largest generator built 2,500 HP.
Largest motor built 1,000 HP.
Noteworthy Specialities:—Machinery and apparatus for very high pressure three-phase tramways, locomotives, complete installations of calcium carbide plant.

3.—The Works of the Maschinenfabrik Oerlikon.

Founded 1871. Company limited 1876.

(Visited Monday, September 4th.)

Number of workmen:—1800.
Number of Staff:—250.
Motive power:—Water power at Hochfelden with 3 turbines of 200 HP.
Electric current transformed up to 15,000 volts and transformed down at works. Distance of transmission 22 kilometres.
Three-phase motors are fed at 190 volts.
Lighting by continuous current 2 × 125 volts.
Number of motors:—94.
Number of lathes and other machine tools:—860.
Number of electric cranes:—18, having a total carrying capacity of about 220,000 kilogrammes.
space of the works 42,038 square metres
belonging to works 118,078 " "
excluding adjoining property.

Departments of the Works:—
and steel foundry.
anical tools.
R. Pow , lifts, etc.
cal machinery:—generators, transformers, and motors.

1. R **ced**:—	Number
2. Zür ools, lathes, etc.	6,300
3. Scha oller mills	14,100
4. Raff es (before 1892)	125
5. Kande rators and motors	15,000
" " " (in 1898)	3,205
Electric Tr rmers	3,000
1. Zürich C locomotives, trams, etc.	330

Zürich-O **s-current dynamo built**:—
Zürich, fa ter 4·5 metres.
" 35,000 kilogrammes.
000 kilogrammes.
machine built:—
th metres.
,000 kilogrammes.
kilogrammes.

Principal Departments of the Works:—Steel foundry, formerly using the Siemens-Martin and crucible processes only, but now employing a converter-process.

Electric welding shops, using the Slavianoff and Benardos processes.

Power Distribution:—By compressed air at 6 atmospheres pressure, for small cranes and tools.

Electrical, from a 500 HP. Sulzer engine, driving a three-phase generator, and distributing at 365 volts to about 45 motors of from 1 to 165 HP.

Speciality:—Soft cast-steel, with magnetic properties similar to those of wrought-iron, especially applicable for electrical purposes; and harder steel castings for various purposes.

8.—The Rüti Silk Weaving Factory (*Mechanische Seidenweberei Rüti*), Zürich.

(Visited Tuesday, September 5th.)

The Introduction of Electrical Driving resulted from the success of an experimental installation put down in 1895 by the Maschinenfabrik Oerlikon to drive 20 of the looms in these works. In 1897 the whole factory was changed over to electrical driving.

Number of Looms:—404.

Motive Power:—Water power by two 30 HP. turbines, and a 70 HP. steam engine.

Electrical Generators:—*For Power*, a 100 HP. three-phase generator rotating at 500 revolutions per minute, and producing a current at 200 volts with a periodicity of 50.

For Lighting, an Oerlikon, 59 HP., four-pole, continuous-current dynamo, rotating at 820 revolutions per minute, and producing a current of 320 amperes at 125 volts. Connected with this generator is a battery of 70 accumulator-cells of 1,404 ampere-hour capacity.

The power- and lighting-systems are kept entirely separate, but [illegible] an arrangement is made by which, if necessary, the exciting-current [illegible] for the three-phase generator may be drawn from the lighting dynamo [illegible] or from the accumulator cells, instead of from its own direct-coupled [illegible] exciter.

Electrical Conductors:—The main cables are carried alo[illegible]g the roof of subways, so high that a man may pass through them, [illegible] built beneath the rooms, and provided with transverse galleries at inte[illegible]rvals. All parts of the conductors and the fuses, which are also placed [illegible] in the galleries, are therefore accessible for repairs, and there are n[illegible] wires or conductors running through the rooms.

Lighting:—In the weaving-rooms incandescent lights [illegible] brought to them carried through iron uprights w[illegible] the other rooms inverted arc-lamps.

Motors:—One motor (940 revolutions per minute) for [illegible] looms ¼ HP., for Jacquard looms and other wor[illegible]

Electric Lift:—An Oerlikon 500-kilogrammes go[illegible] 3 HP. continuous-current motor driven from [illegible] from the accumulators. [illegible]t.).

AREA OF SUPPLY.

Power :—Current is provided for small motors in business quarters, and for the sub-stations at the Tonhalle, and at the physical and chemical laboratory buildings, and for the Post Office.

Light :—All private and public lighting in the town of Zürich.

Trams :—Current either direct or through the sub-station "Selnau" (at present 4—and when other proposed lines are completed 10—lines in use, partly private and partly belonging to the town).

WATER POWER PLANT.

(Property of the Municipal Water Supply.)

The whole of the river Limmat with dam, conveyed by canal to turbines.

Fall :—Varying from 1·5 to 3 metres.

Turbines (including those for the Water Supply) :—10 Jonval Reaction Turbines of 101–150 HP., 2 high-pressure turbines driven from accumulated water at 15 atmospheres pressure, 300 HP. at 200 revolutions per minute. The accumulated water is pumped up into a reservoir for driving the high-pressure turbines.

300 HP. steam engine as reserve, valve regulation.

STEAM PLANT.

Galloway-Boilers, fired with gas-coke.

Horizontal Steam Engines :—

Compound engines with valve regulation.

Tandem „ „ the Frikart method of regulation.

ELECTRICAL PLANT.

System :—Single-phase alternating current, at 50 cycles per second, and 2,000 volts, for light and power.

Three-phase current, at 50 cycles and 2,000 volts, for the tramway sub-station.

Continuous-current, 500 volts, for driving trams direct.

Generators :—The older alternating-current generators are of the Kapp type with rotating armature.

New three-phase generators with stationary windings of the Oerlikon Inductor type.

Parallel running [illegible] in series [illegible] providing of both generators (2 phases of the three-phase current [illegible] for single-phase current).

Conductors [illegible] therefore [illegible]

Conductors entirely underground.

Primary lines with several main leads consisting of [illegible] many cables in parallel are run to the distributing points and from there [illegible] to transformer stations, with a maximum loss of 5 per cent.

Three-phase cable to the converter station is qui[illegible] separate.

Secondary conductors from each single transf[illegible] station are separate but in case of necessity can be switched in p[illegible]allel ; three-wire system 2 × 100 volts.

Transformer stations for 80 to 120 kilowatts wi[illegible] parallel connected transformers of 20 kilowatts.

EXTENSION AND OUTPUT.

Water power:—Minimum 600 HP., normal 1,000 HP., maximum 1,600 HP. Provision for enlarging buildings to utilise the maximum horse power.

Turbines for the water supply:—

4 Low pressure at 175 HP., 6 at 100 HP.
2 High ,, ,, 300 ,, and 2 at 30 HP.

Steam engines:—

1 Steam engine at 750 and 2 at 1,000 HP., total 2,750 HP.
1 ,, ,, 300 HP. for water supply.

Electric Generators:—

4 units of 300 HP., 1 unit at 750 HP. and 2 of 1,000 HP., total 3,950 HP.
1 unit of 300 HP. for continuous current.

Transformers:—

30 stations, 60 transformers at 20 kilowatts, total 1,200 kilowatts.

Conductors	Underground Cables.
Primary, total length of line	12 kilometres.
Length of wire	43 ,,
Greatest distance	6 ,,
Secondary, total length of line	50 ,,
Length of wire	200 ,,

Area of supply by the whole plant about 6 square kilometres.

Lighting:—Connections equivalent to that of 39,000 16-candle-power normal lamps.

Power:—200 motors with a total of 300 HP.
Tram sub-station 3 motors at 300 HP. or a total of 900 HP.

ENGINEERS AND CONTRACTORS.

General supervision of the first electric plant:—**W. Wyssling, Engineer.**
,, ,, of further extensions:—**H. Wagner, Engineer.**

Turbine plant:—**Escher Wyss & Cie., Zürich.**

Steam engines:—**Gebrüder Sulzer, Winterthur, and Escher Wyss & Cie., Zürich.**

Steam boilers:—**Escher Wyss and Cie., Zürich.**

Electric conductors:—**Kabelfabrik Cortaillod (Switzerland) and O. Bondy (Vienna).**
(Additions made by the company itself.)

Electric generators:—**Maschinenfabrik Oerlikon.**

Transformers:—**Maschinenfabrik Oerlikon and Brown Boveri & Cie., Baden.**

Motors:—**Maschinenfabrik Oerlikon and Brown Boveri & Cie., Baden.**

Installations for lighting:—**The town works of Zürich, Stirnemann & Weissenbach, Zürich, and several others.**

3.—Municipal Electric Supply, Schaffhausen.
(Elektricitätswerk der Stadt Schaffhausen.)

Built 1896—1897. Opened February, 1897.

(Visited Tuesday, September 5th.)

DRIVING POWER.

Water power from the Rhine, normal 1,500 HP., reserve 300 HP. Station in the town on the left bank.

AREA OF DISTRIBUTION.

... Schaffhausen ...

WATER POWER PLANT

ELECTRIC PLANT.

... underground and have ...

... underground in the town and on the ... are on the three-wire system and ... in the centre of the ... volts.

EXTENSION AND OUTPUT.

Water power ... supply, normal 600 HP., maximum
... normal 600 HP., maximum 000 HP.

... supply, 2 of 500 HP., to be ... 500 HP.

... and 20 KW., total 440 KW. in ... low pressure
... high pressure).

... lamps total 7200, besides ... metres.

... 12,000 metres.
... 24,000 ...

[redacted]

Secondary.	Overhead.	Underground cables.
Total length of line	13,000 metres	7,200 metres
Length of wire	39,000 „	14,400 „
Weight of copper	4,800 kilogr.	

ADDITIONAL NOTES.

Turbines with vertical shafts 48 revolutions per minute. Geared to the horizontal shaft of the generators through bevel cog-wheels to 170 revolutions per minute.

Electric generators and exciters:—Oerlikon inductor type, with stationary windings, horizontal shafts, two bearings. Armature coils shaped on formers and laid in slots.

Power absorbed = 300 HP., Speed = 170, Weight = 16,000 kg.

Efficiency including excitation at full load 92 per cent. Fall in voltage in lamps 6 to 8 per cent.

Each generator has an exciter, belt-driven from the generator shaft; exciter output sufficient for two generators, but usually generators are excited each from its own exciter.

Hand regulation of voltage.

There are concentric high-tension cables of 60 sq. mm. leading from generators, with switches, fuses, &c.

Electric conductors:—Loss in primary conductors 3 per cent. maximum.
„ „ secondary „ 2 „ „

In the more crowded part of the town two wires; and in the suburbs three wires carried on overhead poles.

Transformer stations:—1 underground station for 4 transformers of 20 KW.

10 Stations in buildings each to take 2 transformers of 20 KW.

11 Stations in separate houses each for 2 transformers of 20 KW.

Transformers in two sizes:
6 units of 10 KW.
19 „ „ 20 KW.

Motors:—Induction motors without slip rings 1·5–6 HP.

Two high-pressure motors of 33 HP. with slip rings and starting resistances in armature circuit.

740 revolutions per minute. 50 cycles, 1,900 volts, wound as three-phase motors, and running temporarily as single-phase motors for driving centrifugal pumps.

ENGINEERS AND CONTRACTORS.

General Supervision:—**Aug. Habicht, Engineer, Schaffhausen.**
Turbine plant:—**Escher Wyss & Cie., Zürich.**
Electric generators:—**Maschinenfabrik Oerlikon.**
Cables:—**Société d'exploitation des Cables électriques, Cortaillod.**
Transformers:—**Maschinenfabrik Oerlikon.**
Motors:— „ „
Installations:—**The company itself and other firms.**

4.—Rathausen Central Station near Luzern.

Elektrizitätswerk Rathausen, Aktiengesellschaft, Luzern.

Built November, 1894—1896. Opened July, 1896.

DRIVING POWER.

Water power in **Rathausen** on the Reuss (1·5 kilometres below the mouth of the Kleine Emme).

Steam power as reserve.

AREA OF DISTRIBUTION.

Power provided for factories and small businesses in Luzern, Kriens, Emmenbrücke, Emmen, Emmenweid, Inwil, and Hochdorf, as also for the tramways (converter station with accumulators).

Lighting in the above districts and partly in Lucerne (Railway station, etc.).

WATER POWER PLANT.

Fall varying from 4–5 metres.

In summer 1,500, in winter 1,200 HP.

5 double-bladed wheel reaction turbines 300 HP. each.

Weir:—40 metres broad (40 clappers 1·2 metres broad and 1·4 metres high, only used at low water).

Canal:—32 metres broad and running almost parallel with the Reuss.

8 sluices of 4 metres in length and 5·2 metres high.

Canal 1,200 metres long ; at entrance, 22 metres broad and 1·75 metres deep ; below, 11 metres broad and 3 metres deep.

In front of the grated door the canal is broadened to 29 metres. The division between the canal and the river Reuss is a concrete wall built on rock foundation.

Fall 1·4 ‰. Speed of water 1 metre at a surface fall of 6·3 ‰. In front of the sluice is an overfall 30 metres broad, and 300 metres above the engine house is an automatic overfall which opens if there is any sudden rush of water.

The canal beyond the turbine house is 1,200 metres long and 20 metres broad at the bottom. The wall is of concrete.

Machine room:—Built on a foundation of rock and bedded with concrete to the level of the machine room floor. 5 turbine chambers. Building situated on the right bank of the canal, with space for a sixth turbine. Overhead crane of 12 tons capacity in the turbine house, another of 12 tons for the steam-engines.

South wing of the machine room 51·6 metres long, 9·3 metres broad and 10·9 metres high.

East wing (steam) 24·8 metres long, 14·6 metres broad and 12·9 metres high. Cubic contents of the whole room 8,540 cubic metres.

6 HP. turbine for working the revolving sluices. Workshop in the south part of the building.

Regulation of Turbines:—The inner wheel with balanced ring sluice is regulated by a patent automatic regulating device, whereby the working is performed according to geometrical progression, so that the regulated speed remains constant at each variation of load.

STEAM POWER PLANT.

1 tandem machine 350 HP. with valve regulation. Coal house and boiler house built on to the turbine house, and constructed for 5 boilers; at the present time 2 combined multi-tubular boilers are installed.

Chimney 47 metres high.

ELECTRICAL PLANT.

Two-phase current (3 wires). 3,200 volts per phase. Power and light cables separate, but can be connected in parallel if required. In the same way the generators can work in parallel or singly on any chosen circuit.

Near "Eichhof" (between Luzern and Kriens) is a primary transformer station with reduction of 3,000 to 1,500 volts.

Cable connection with the town through 8 transformers of 25 kilowatts.

Generators: 60 revolutions and 40 cycles, magnet wheel direct-coupled to an extension of the turbine shaft.

Armature stationary.

One generator with rotatory field bolted direct to the crank-shaft of the steam-engine and constituting the fly-wheel. Armature stationary, inside.

15 HP. exciters are fixed on to the side of each generator and driven by cog-wheel gearing from the turbine shaft at 450 revolutions per minute; 70 volts.

The steam-dynamo exciter is keyed on to the end of the crank-shaft and has an output of 15 HP. at 120 revolutions; 70 volts.

The efficiency of the generators at full load is about 90% and at half load about 87%.

Switchboard of 11·3 metres breadth and 4·8 metres height.

Each conductor can be tested to earth when the circuit is closed.

In the space between the turbine-chambers and the machine-room are separate passages for the conductors which lead from the generators to the switchboard.

Primary conductors in the open air are fixed on brown "three bell" insulators on the system Sihlwerk of Wädensweil.

Length of the poles 10–18 metres, average distance apart 38–40 metres. Embedded in concrete sockets when the ground is unfavourable.

The primary lines cross the state wires (*i.e.* telephone and telegraph) 19 times.

The secondary lines cross the state wires (telephone and telegraph) 18 times.

There are 24 crossings over the railways; and 8 below railways: in two cases the wires are led down an iron framed tower, under the railway and up again on a similar tower placed on the opposite side of the railway. Conductors are mounted on bell-shaped insulators.

Forked lightning arresters behind the switchboard and at all end stations.

Secondary voltage for power 2×250 volts, for lighting 125 volts (motors of 50 HP. upwards work on the high-pressure circuit).

EXTENSION AND OUTPUT.

Water power:—Minimum 1,200 HP., normal 1,500 HP., maximum 1,800 HP.

Water plant:—Built to develop 1,800 HP.

Building:—Laid out for 2,500 HP.

Erected:—5 turbines at 300 HP. and 1 steam engine at 350 HP.

Electric generators :—5 at 300 HP. and 1 at 350 HP. = total of 1,850 HP.
Transformers :—118 from 3–25 kilowatts, total 199 kilowatts in 29 stations.
In stations of more than 5 kilowatts capacity 2 or more tranformers are installed.
Power :—8 motors with total of 710 HP. (high pressure).
85 ,, ,, ,, 924 ,, (low pressure).
Altogether 93 motors from ½–200 HP. with total of 1634 nominal HP.
Lighting :—Expressed in 16 CP. :—3,400 incandescent lamps ; and 138 arc lamps besides.
Area of supply about 70 square kilometres and about 5·6 square kilometres for secondary circuit.

Primary conductors :—	Overhead conductors.	Underground cables.
Length of line (3–15 wires)	30·8 km.	2·9 km.
Length of conductor	171·1 ,,	8·7 ,,
Greatest distance	12·2 ,,	8·7 ,,
Weight of copper	46 tons	
Secondary conductors :—		
Length of line	15 km.	0·8 km.
Length of conductor	53·7 ,,	1·8 ,,
Weight of copper	11 tons	

ENGINEERS AND CONTRACTORS.

General supervision :—**Engineer R. Isaak, Luzern.**
Mechanical and electrical plant :—Installed under the direction of **P. Lauber, Engineer, Luzern.**
Weir and entrance channel :—**Fietz & Leuthold, Zürich.**
Canal :—**G. Toneatti, Kriens.**
Turbine house :—**Fietz & Leuthold, Zürich.**
Steam engine house :—**Architect H. Siegwart, Luzern.**
Turbine plant, cranes, transmission, etc. :—**Th. Bell & Cie., Aktiengesellschaft, Kriens.**
Steam engines :—**Gebrüder Sulzer, Winterthur.**
Steam boilers :—**Th. Bell & Cie., Aktiengesellschaft, Kriens.**
Transmission lines :—**The Company itself.**
Cables :—**Feltens & Guilleaume,** also **Siemens & Halske.**
Electric generators :—**Brown Boveri & Cie., Baden.**
Transformers :—**Elektrizitätsgesellschaft Alioth, Münchenstein and Brown Boveri & Cie., Baden.**
Motors :—**These two firms.**
Installations :—**The Company itself.**

5.—The Central Station on the Kander.

Headquarters in Thun.
Owner : "Motor," Aktiengesellschaft für angewandte **Elektrizität in Baden.**
Built 1897–1899. Opened in June, 1899.

(*Visited Saturday, September 9th.*)

DRIVING POWER.

Water power from the river Kander, generating station **near Spiez on the lake of Thun.**

AREA OF DISTRIBUTION.

Power and light supplied to the towns of Bern and Burgdorf and to the districts of Münsingen and Spiez.

Railway between Burgdorf and Thun (full normal gauge).

WATER POWER PLANT.

The water of the whole Kander at Spiezwyler.

Fall to the lake 69 metres.

Dam, height variable according to volume of water.

Sluices with arrangement for preventing obstructive material passing.

Open canal :—678 metres long.

Tunnel :—857 metres long and about 4 metres sectional area.

Sheet metal pipe :—988 metres long to a reservoir pipe with diam. = 1,800 millimetres; from reservoir to turbine house are two pipes 1,600 millimetres diam.

Turbine house close to the lake edge.

Turbines with horizontal shafts and shell-shaped shovels, with automatic speed and pressure regulators (automatic no load) and artificial automatic air passages.

ELECTRIC PLANT.

System :—3-phase alternating-current generated at 4,000 volts. Separate for regular and irregular use.

Distribution in the immediate neighbourhood (to about 10 kilometres) with this voltage.

Step-up transformer house to 16,000 volts.

Secondary circuits different, as follows :—

In Bern :—Three-phase current and (omitting 1 phase) single-phase current, transformed to 3,000 volts and distributed into the mains where it is generally transformed down to 2 × 120 volts (three-wire system) in small sub-stations.

In some cases three-phase motors at 3,000 volts convert the current to continuous-current at 600 volts.

In Burgdorf :—Current transformed from 16,000 to 500 volts, and at one converter station (three-phase motors coupled to continuous-current dynamos) for service in the town. Elsewhere motors are driven from the three-phase current.

In Münsingen :—Current transformed from 16,000 to 4,000 volts. Transmission through overhead wires and again transformed down for the incandescent lamps.

For the railway Burgdorf-Thun :—Current is transformed from 16,000 to 750 volts, part is again reduced to 120 volts for lighting. (See Burgdorf-Thun-Railway, p. 224.)

Generators of 900 HP. at 300 revolutions per minute direct-coupled by flexible couplings to the turbines, 4,000 volts, 40 cycles.

Rotatory field, stationary armature with stamped holes.

Exciters direct-coupled and fastened to generators.

Excitation of fields is in each case provided with current from 1 dynamo driven by a separate turbine.

Switch arrangements :—Bus bars can be disconnected in different parts fo separating the regular and irregular load. Generators can be switch

in as required. Switchboard can be divided into two halves to allow of repairs when circuit is closed.

Transformers in separate buildings for transforming 4,000 volts up to 16,000 volts.

Reserve transformer to be switched in to any phase.

All single-phase transformers in oil with water cooling. Each 300 KW. with 2 vertical cores in closed cast-iron cases.

Conductors:—From the power-station all conductors are overhead and bare, mounted on porcelain bell-shaped insulators; as far as the river Aar near Thun all conductors are carried on iron towers, which are fitted with oak blocks, on to which the insulators are fixed. From this point on fir-tree poles.

Distance to Burgdorf and to the furthest point in Bern about 47 kilometres.

To Burgdorf and for the railway are 3 wires: to Bern, 3 for motors and 2 for lighting.

Lightning arresters of the horned type connected to water resistances at the ends of the lines.

Transformers for 16,000 volts in Bern, Burgdorf, and Munsingen 50 KW. capacity.

Single-phase with 2 vertical cores laid in ribbed cases filled with oil, without further cooling. (Further details given under Burgdorf-Thun-Railway, p. 224.)

EXTENSION AND DETAILS.

Water power:—Minimum 2,500 HP.; normal 4,500 HP.
Maximum 5,400 HP.

Water course, &c.:—Provided for an aggregate of 6 machines = 5,400 HP.

Turbines:—4 at 900 HP. Total 3600 HP.

Electric generators:—4 generators of 900 HP.

Exciters:—2, one being a reserve.

Transformers:—

Primary 4,000/16,000 volts:—8 single-phase of 300 KW. = 2,400 KW.

Secondary 15,000/3,000, 4,000 and 5,000 volts.

in Bern 16 of 50 KW. = 800 KW.

in Burgdorf 7 of 50 KW. = 350 KW.

in Münsingen 3 of 50 KW. = 150 KW.

Primary 4,000/120 volts in Spiez

2 of 20 KW. } = 60 KW.
2 of 10 KW. }

Burgdorf-Thun-Railway:—

Primary 18,000/750 volts, 14 of 150 KW. = 2,100 kilowatt

Conductors:— Overhead in the open.

Primary:	Total length of line	100 km.
	Length of wire	564 „
	Greatest distance	47½ „
	Weight of copper	100 tons.

ENGINEERS AND CONTRACTORS.

Supervision:—Officials of the company.

Water course:—Locher & Cie., Zurich.

[illegible]:— „ „ „ „

Turbine plant :—Escher Wyss & Cie., Zürich.
Electric conductors :—Brown Boveri & Cie., Baden.
Electric generators :— " " " " "
Transformers :— " " " " "
Motors :— " " " " "

C.—ELECTRIC TRAMWAYS AND RAILWAYS.

1.—The Zürich City Tramways

(Owned by the Municipality of Zürich).

(*Visited Monday, September 4th.*)

10 kilometres horse-car lines.
11 kilometres electric street car lines. Total length of electric tramway lines, 18 kilometres.
The first portion built of the electric lines was a private undertaking in 1893. Extensions by the Municipality 1898–99. Conversion of the horse-tramways into electric tramways now in progress.

DRIVING POWER.

1. For electric tramways east of the Limmat.
   a. Steam engine plant at station "Burgwies," Zürich V.
   b. Gas engine plant at station "Fluntern," Zürich IV.
2. For electric tramways west of the Limmat.
   c. Converter station "Selnau," Zürich I, with motor-generator sets driven from the city central station (see "The Central Station, Zürich," p. 205).

ROUTE.

Electric Trams :—Burgwies-Kreutzplatz-Bellevue-Paradeplatz.
Bahnhof Enge-Bellevue-Römerhof-Kreutzplatz-Hauptbahnhof.
Hauptbahnhof-Sihlbrücke-Heuried.
Horse Trams :—Tiefenbrunnen-Bellevue-Helmhaus-Hauptbahnhof-Paradeplatz-Enge.
Helmhaus-Paradeplatz-Sihlbrücke-Aussersihl.

ELECTRIC SYSTEM.

Continuous current, 550 volts, overhead trolley with return through rails.

DETAILS.

Power Stations:—(1) Burgwies: 2 steam engines of 90 HP. and of vertical

type, belted to two compound-wound generators with accumulators connected in parallel to act as buffer battery.

The accumulator battery consists of 300 Tudor cells in series, for 277 ampere-hours capacity and 81 amperes maximum discharging current.

Automatic cut-out. Booster for charging cells.

This plant was the first ever installed with an accumulator buffer battery for electric tramways.

The power station is at present being enlarged, and a Sulzer compound tandem steam-engine of 250 HP. at 90 revolutions per minute is being installed. This engine is directly connected to an Oerlikon compound-wound generator.

New boosters and boiler are also being installed.

(2) Fluntern :—This power station is owned privately.

Dawson gas-plant, one gas-motor of 120 HP., and three gas-motors each of 60 HP. belted to compound continuous-current generators of corresponding size.

Buffer battery of 515 ampere-hours capacity.

(3) Selnau :—3 three-phase motors of 300 HP. (2,000 volts working pressure) directly connected to 3 continuous-current generators of corresponding size. No accumulator battery.

Tramway:—Gauge one metre. Minimum radius of curves, 15 metres. Maximal inclines, 65‰, 80 metres long ; 50‰, 258 meters long.

Rails:—Longest rails 12 metres. Phœnix rails, profile 7b, were adopted for the old electric lines. These rails are gradually being taken out and replaced by Phœnix rails of profile 18c, which are used extensively for the new lines and re-laying the horse-tramways.

Bedding of quarry stones, 50 centimetres by 25 centimetres, placed under length of rails.

Weight per metre of rail (Phœnix 18c)	49·4	kilogrammes.
„ „ tramway „	112·4	„

Switches and crossings made out of rails.

Electric Conductors:—The old lines have been entirely reconstructed on the same principles as the new.

Underground lead-covered feeding cables, system Berthoud-Borel, in burned clay channels.

Contact trolley wires everywhere doubled, 2 hard copper wires of 8 millimetres diameter, 6 metres minimum distance above rails.

Wires supported by Mannesmann steel tube masts and hooks in the walls of the houses. Standard distance between points of suspension, 35 metres.

Trolley wire system split up in sections, each about 1,000 metres long in centre of town, and about 1,800 metres in suburban parts.

Each section is separately fed, and the corresponding section of rails has separate return cables. Trolley-wire sections can be connected at will through section switches.

Electric rail bonds, type "Bryan" and "Edison-Brown," both applied with Edison alloys.

Rolling Stock:—Cars: 45 tram-cars, each with 2 axles and 2 motors with single gear reduction. Series-parallel speed regulation.

50 new tram-cars now being built with Peckham trucks, 2 axles, entirely enclosed platforms and equipment as above.

Car equipment:—Motors of type Oerlikon, Walker, and G.E. 60, with corresponding controllers.

For the new cars a standard equipment of 2 G.E. 60 motors, 2 S1-Walker

controllers and 3 Union resistances has been selected. Each car is fitted with 2 automatic cut-outs, copper fuse, lightning arrester, choke coil, Nuttall trolley base, etc.

Car sheds:—At Burgwies, Heuried, Seefeld and Aussersihl.

Running:—At 3 minutes intervals, and with maximum speed of 12 kilometres per hour; and at 6 minutes intervals and 18-kilometre speed in the suburban portion of the route.

Repairs:—All repairs made in own repair shops.

ENGINEERS AND CONTRACTORS.

General supervision:—**P. Schenker, M.E., with the assistance of J. S. Edström, E.E.**

Contractors for bedding:—**Th. Bertschinger of Lenzburg.**

" " rails:—**The Phœnix Company of Laar near Ruhrort.**

" " trolley wire system:—**Maschinenfabrik Oerlikon.**

" " rolling stock:—**Schweizerische Industriegesellschaft of Neuhausen, and Geissberger & Co., Zürich.**

Tram-car motors (see above) and car equipment; electric rail bonds, etc. by own staff.

2.—Electric Tramway: Zürich-Oerlikon-Seebach.

Limited company, Zürich IV.

Built 1897, and opened on 22nd October, 1897.

(Visited Monday, September 4th.)

DRIVING POWER.

Gas is produced, in a building adjoining the generating station, by a Dowson gas plant.

The line starts from Bahnhof-Brücke in Zürich and runs to the railway crossing at Oerlikon, at the other side of which is a connection to Seebach.

ELECTRIC SYSTEM.

Continuous current at 550 volts.

Overhead wire and trolley, return through the rails.

EXTENSION AND DETAILS.

Central Station:—2 gas generators of 100 HP., and 1 at 200 HP. Three steam boilers, capacity 200 HP. Anthracite coal.

Gas motors:—3 horizontal single-cylinder gas-motors of 125 HP. at 180 revolutions per minute.

Dynamos:—3 compound-wound continuous-current dynamos direct-coupled to the gas engines, 180 revolutions per min., 550 volts, and 4 poles. Armatures drum-wound, copper commutators with carbon brushes.

Accumulator battery connected in parallel with the dynamos, being alternately charged and discharged by the trams. 280 Tudor cells in series, having capacity of 370 ampere hours. Cells automatically cut out.

Reserve dynamo (converter 550/150 volts) for charging battery.

Tram lines :—Total distance 5,500 metres.

Length of tramway	8,000 metres.
Gauge between rails	1 metre.
Minimum curve radius	25 metres.

Rise :—Maximum, 64 ‰ ; average, 11·3 ‰.

Rails :—In the town of Zürich :—Phœnix rails, profile 14b.

Weight for railway per metre 90 kilogrammes, and for rail per metre 42·5 kilogrammes. Rails laid on stone bedding 25 centimetres deep.

Outside the town (from 1·7 kilometre on) profile 5, rails weighing 33 kilogrammes per metre laid on iron sleepers, 8 to 10 metres of rail.

The Electric Conductors :—Distance divided :—

1. Zürich Central station, direct-connected and with feeders 250 millimetres below surface, 2,400 metres long.
2. Generating station Seebach, direct-connected with tram-lines.

Thomson's lightning arresters at station and at the end of feeding cable.

Contact wire :—Double contact wire 8 millimetres diameter fixed on wire stretched at right angles.

Minimum height above rails is 6 metres.

Iron masts (outside the town sometimes wood).

Rolling Stock :—20 tram-cars, with two axles, 20 seats inside and with two platforms for 8 persons, 8 brakes on car.

Electrical equipment :—2 motors of 18 HP. at 450 revolutions.

Gear-reduction 1 : 4·5. Voltage 550. Regulation by series-paralled switch with 7 contact points for forward and backward motion. On these controllers are contacts for an emergency brake. The Resistance is of sheet-iron ribbon.

2 safety fuses and lightning protector.

Running :—Trams run from 5 a.m. till 11 p.m., with 6 minutes intervals between cars.

Speed, maximum 25 kilometres per hour.

10 cars running on week-days ; 18 to 20 on Sundays.

Results of traffic :—Each tram-car travels 1,610 kilometres per day.

Passengers per car-kilometre, 3·2.

Income per car-kilometre 43 centimes.

Cost per kilometre is 34·4 centimes.

Coal consumed per eff. HP. hour of the gas-motors 0·65 kilogramme (Anthracite coal).

ENGINEERS AND CONTRACTORS.

General supervision :—**Maschinenfabrik Oerlikon** for the whole plant.

Buildings :—Ingenieur **J. H. Kuhn in Zürich.**

Road :—**Th. Bertschinger of Lenzburg.**

Rails :—**Phœnix Company in Laar near Ruhrort.**

Machine equipment, Power station :—

Dowson-gas plant :—**Gasmotorfabrik Deutz.**

Gas machines " "

… hinery :—**Maschinenfabrik Oerlikon.**

A… :—**Accumulatorenfabrik Oerlikon.**

[redacted]

Rolling stock :—

Tram-cars :—**Schweiz. Industriegesellschaft Neuhausen.**
Electric motors, fittings, etc. **Maschinenfabrik Oerlikon.**
Overhead contact lines, etc. „ „
Repairing shops „ „

3.—Electric Tramway in the Industriequartier Zürich.

Limited Company in Zürich III.
Built 1897–1898. Opened April, 1898.

Driving Power :—Current from the Zürich central station.
Route :—Bahnhofplatz Zürich to Limmatbrücke near Wipkingen.

ELECTRIC SYSTEM.

Continuous current, 550 volts, overhead trolley-wire, return through rails.

EXTENSIONS AND DETAILS.

Power Station :—Continuous-current machine from the central station in Letten. No accumulators.
Route :—2,100 meters long.
Gauge between rails, 1 metre.
Minimum radius of curve, 18 metres.
Maximum rise, 50‰.
Rails single track with 5 sidings.
Phœnix rails, profile 14b, weight per metre 42 kilogrammes.
Weight of tramway per metre 94·6 kilogrammes.
Electric Conductors :—Contact wire 8 mm diameter, everywhere double. Mannesmann iron masts.
Rolling Stock :—9 tram-cars with 2 axles and 2 motors of 18 HP. Regulation by series-parallel switches.
Running at intervals of 6 minutes.

BUILDERS.

Whole electrical equipment :—**Maschinenfabrik Oerlikon.**
Cars (alone, without electrical equipment) :—**Waggonfabrik Neuhausen** (Switzerland).

4.—Electric Tramway Luzern.

(Owners : Politische Gemeinde Luzern.)

In course of construction.

DRIVING POWER.

Two-phase electric motors at 2,300 volts in the converter station of **Steghof, current supplied from the central station of Rathausen.**

ROUTE.

Maihof-Bahnhof-Untergrund and Haldenstrasse-Bahnhof-Kriens.

ELECTRIC SYSTEM.

Continuous-current 575 volts, overhead contact wires and trolley, return through rails.

EXTENSION AND DETAILS.

Power Station (converter station) :--Separate building, containing :—

2 motor-generator groups, consisting of 2-phase motors 2,300 volts 150 HP. and continuous-current shunt-wound generators 90 KW. 575 volts, 470 revolutions.

1 Accumulator-battery 270 Tudor cells of 198 ampere-hours capacity, connected in parallel with continuous-current dynamos, as buffer battery.

Route :—Maihof-Bahnhof-Untergrund :--2,500 metres.

Haldenstrasse-Bahnhof-Kriens :—4,700 metres.

Total length of tramway :—9,700 metres.

Rise maximum 45 $^{0}/_{00}$, average 6 $^{0}/_{00}$.

Gauge 1 metre. Minimum radius of curve 25 metres.

Tram lines :—Single track with sidings.

Phœnix rails profile 25 with cross bars.

Straight joints.

Weight per metre of rails 48·5 kilogrammes; and per metre of tramway 114 kilogrammes.

Bedding of stone 30 centimetres deep.

Electric Conductors :—Double-contact wires 8 millimetres in diameter of copper. Height 6 metres above ground. Mannesmann masts.

6 subdivisions, each separable. Feed and return conductors underground.

2 feeders of 250 square millimetres to the Bahnhof.

1 return cable of 250 square millimetres to the Bahnhof.

1 feeder of 200 square millimetres to railway station Gütsch.

2 feeders to Birsigstrasse.

Rolling Stock :—20 tram-cars, with 2 axles, 16 seats inside, room for 14 standing on the platforms. 8 brakes.

Electrical equipment :—2 motors with gears of 25 HP., series wound 500 volts, 400 revolutions, gear ratio 1 : 4·5, regulation by series-parallel switch with 8 points, 2 automatic cut-outs. Trolleys with side movement.

Tram-cars electrically heated.

Car house in the Birsigstrasse, adjoining the converter station, holds 30 cars; repairing shops, offices, &c., in the same building.

Running at intervals of 7½ minutes.

ENGINEERS AND CONTRACTORS.

Contractors and authors of the scheme :--**Maschinenfabrik Oerlikon.**

Buildings :—**Architect Professor Schneider, Luzern.**

Tramway :—Rails by the **Aktiengesellschaft Phönix in Laar near Ruhrort.**
Laid down by the **N. Bosshardt, Zürich.**

Converter station :—

Electric machinery :—**Maschinenfabrik Oerlikon.**

Accumulator batteries :—**Accumulatorenfabrik Oerlikon.**

[redacted]

Rolling stock :—
  Cars :—**Schweiz. Industriegesellschaft Neuhausen.**
  Electric equipment :—**Maschinenfabrik Oerlikon.**
Overhead conductors :— „ „
Cables :—**Kabelfabrik Cortaillod.**
Repairing shops :—**Maschinenfabrik Oerlikon.**

5.—The Stansstad-Engelberg Electric Railway.

Elektrische Bahn Stansstad-Engelberg, Aktiengesellschaft in Stans.

Built 1897–1898. Opened in September, 1898.

(*Visited Thursday, September 7th.*)

DRIVING POWER.

Water Power:—Spring with reservoir, 415 metres above the power station Obermatt.

ROUTE.

Stansstad-Stans-Engelberg, a part of which from Obermatt to Gherst is laid with rack, the rest with adhesion rails.

ELECTRIC SYSTEM.

Three-phase alternating current at 750 volts from generators direct on to the trolley wire. For the other end current raised to 5,000 volts by two step-up transformers and transmitted on overhead conductors to 2 transformer stations in Dallenwyl and Stans and there transformed back to 750 volts.

In addition there are special feeders taken from the generator station and transformer station.

Two overhead contact wires, the third being the rails; current collected by two bows.

EXTENSION AND DETAILS.

Power Station:—3 generators of 180 HP. coupled direct to high-pressure turbines, with a reserve.

2 separate exciters of 12 HP. direct-coupled to high-pressure turbines, one reserve.

Generators with revolving armatures, holes stamped.

3 single transformers at 30 kilowatts 750/5,300 volts.

Liquid resistance used to take loads during descent of cars.

2 secondary transformer stations having 3 single-phase transformers of 30 kilowatts at Dallenwyl and Stans.

Route:—Total length 22,500 metres.
  Gauge 1 metre.
  Rise :—Maximum on the adhesion track 50 ‰.
    Maximum „ „ rack line 250 ‰.

Tram Lines:—System Vignole-Adhesion rails, rack system Riggenbach.

The Electric Conductors:—Circuit breakers in the trolley line.
Wooden masts used throughout, telephone wires on the same masts.

Rolling Stock:—7 cars each with 3 asynchronous motors of 35 HP. (total 490 HP.) and with single-gear reduction.
Speed regulated by resistance inserted in the rotor circuit, by means of slip-rings and brushes.
Electric heating and lighting by special transformer in car.
3 electric locomotives with motors of 150 HP. (total 450 HP.) regulation as in the above case.
Wagons for carrying goods.
Each locomotive is fitted with several mechanical hand and automatic brakes.

ENGINEERS AND CONTRACTORS.

Supervision :=**Locher & Cie., Zürich, and Brown Boveri & Cie., Baden.**
Canal :—**Locher & Cie., Zürich.**
Buildings :— " " " "
Turbine plant :—**Th. Bell & Cie., Aktiengesellschaft, Kriens.**
The electric plant :—**Brown Boveri & Cie., Baden.**
Electric generators :— " " " " "
Transformers :— " " " " "
Motors and other electrical equipment also rolling stock :—**Brown Boveri & Cie., Baden.**

6.—The Jungfrau Railway.

Jungfraubahn, Aktiengesellschaft in Zürich.

In construction since 1897. A part opened in the summer 1898.

(*Visited Friday, September 8th.*)

DRIVING POWER.

Water power from the White Lütschine near **Lauterbrunnen.**

ROUTE.

Wengernalp-Jungfrau. At present trains run from Wengernalp to Eigerwand (3 kilometres).

ELECTRIC SYSTEM.

Three-phase current with 7,000 volts transmitted from generators by overhead wires.
Transformed to 120 volts for the lighting of Lauterbrunnen and Wengen, for boring, and at stations.
Transformed to 500 volts for locomotives and building purposes.
2 overhead contact wires, third through rails.
Connection made by 2 trolleys, and slide contact-maker.

EXTENSION AND DETAILS.

Power Station :—Fall 40·8 metres, dam, sluices and grated doors, iron pipe 1,630 + 700 metres long.

Machine house for 4 turbines of which 3 are of 500 and 1 of 800 HP., System "Girard" with horizontal shafts and having two wheels at 380 revolutions.

2 turbines of 25 HP. at 600 revolutions for excitation; all turbines automatically regulated.

Electric Generators :—2 units of 500 HP. and 1 of 800 HP. coupled direct (and insulated) to turbines.

380 revolutions per minute, 38 cycles, 7,000 volts, three-phase current.

Inductor type (stationary windings), high pressure, prepared and formed and then laid in slots.

Exciters :—2 of 25 HP., shunt wound, direct-coupled to separate turbines.

Switching arrangements for parallel running and voltage regulation by exciter voltage, for three-phase or single-phase current (the latter case for lighting with one-phase).

Primary Conductors :—Throughout bare wire overhead, on three-fold porcelain bell insulators mounted on masts of wood, with a maximum of 10 % loss. Power and light separate.

There is a line length of 10 kilometres for the railway and also 3 kilometres for lighting.

The wires from generator station to railway have a rise of 1,500 metres.

Lightning Protectors :—Siemens & Halske horned-type lightning protectors at each end of the conductors, and on every pole is a pointed wire connected to the earth.

Transformer station in separately built houses, differing according to the lighting requirements.

For the railway are two (later 3) transformers of 200 KW., 500 volts secondary pressure; in the lower part of the railway they are 2 kilometres apart, in the upper part (in tunnel) a station at each kilometre.

Transformers with 3 vertical iron cores, primary and secondary coils placed conaxially over one another.

Contact wire of the railway :—Two wires of 9 mm. diameter of hard-drawn copper fixed to wires drawn at right angles to contact wire, insulated and mounted on wooden masts. These masts also carry the feeders.

Rails, joined by railbonds, from the third conductor.

Present route :—

Open way	2 kilometres.
Tunnel	1 "
Gauge	1 metre.
Vignole rails and rack.	

Average rise on the open 120 ‰.
" " in the tunnel 250 ‰.

Rolling Stock :—4 locomotives so arranged that part of the wagon rests on the locomotive; each locomotive has 2 motors with a maximum output of 200 HP.

Electrically heated and lighted.

Electromotors :—8 small motors with three-phase current for driving ventilators, pumps, etc. in tunnel work, altogether 50 HP.

Rock-boring machines :—Electrical percussion boring machines on the solenoid principle, continuous current, 6 machines being worked in the tunnel and 6 in reserve.

ENGINEERS AND CONSTRUCTORS.

Supervision :—**Jungfrau railway, Head engineer Gobat.**
Buildings of water course :—**Gobat & Strub, Head engineers.**
Iron pipes :—**Aktiengesellschaft J. J. Rieter.**
 „ „ **Escher Wyss & Cie.**
Buildings :—**Jungfrau railway, Head engineer Gobat.**
Turbine plant :—**Aktiengesellschaft J. J. Rieter.**
 „ „ **Escher Wyss & Cie.**
Electric conductors :—**Jungfrau railway, Electrical engineer Lomsché,** Installed by **F. Füchslin, Aarau.**
Electric generators :—**Maschinenfabrik Oerlikon.**
Transformers :— „ „
Locomotives :—**Lokomotivfabrik Winterthur, Brown Boveri & Cie., Baden, and Maschinenfabrik Oerlikon.**
Motors :—**Maschinenfabrik Oerlikon and Brown Boveri & Cie., Baden.**
Lighting installations :—**Jungfrau railway, Electrical engineer Lomsché.**
Boring machines :—**Elektrizitäts-Gesellschaft Union, Berlin.**

7.—The Burgdorf-Thun Electric Railway.

Elektrische Vollbahn Burgdorf-Thun, Aktiengesellschaft in Burgdorf.

Built 1897–1899. Opened July, 1899.

(Visited Saturday, September 9th.)

DRIVING POWER.

Water power at the Kander station (see p. 212).

ROUTE.

From Central-Bahn-Bahnhof Thun over Konolfingen (crossing the Bern-Luzern-Railway) to the Central-Bahn-Bahnhof Burgdorf, the route Burgdorf-Hasle is worked in common with the Emmenthal steam railway. The gauge is normal and the railway has its own line of rails.

ELECTRIC SYSTEM.

Three-phase current. Tension of 4,000 volts at the Kander station and raised to 16,000 volts. Transmission by overhead lines along the railway to the transformer stations, and there reduced to 750 volts.

Two contact wires and the rails form the three leads. Trolley of the bow type.

EXTENSION AND DETAILS.

Power Station :—(See Kander central station.)
Route :—Total length of line 40,000 metres. Three tunnels together 350 metres long. Railway 536 to 770 metres above sea-level.
3 large iron wires, 15 and many small ones.
Gauge norby 2 tre

Minimum radius of curve 250 metres.
Maximum rise 25 ‰.

Rails:—Cast-steel Vignole profile, weighing 36 kilogrammes per metre on iron sleepers for ⅓ of the distance;
wood " " ⅔ " " "

Electric Conductors:—High-tension conductors separate, not always following the railway, mounted on wooden poles. Nearest point (starting point) of the railway 9 kilometres from the Kander power station.

3 wires of 5 mm. diameter copper.

45 metres average distance between masts. 5 % maximum loss.

49 kilometres length of line and 27 tons weight of copper.

Contact wire, 750 volts, 2 overhead wires, hard copper 8 mm. diameter; holding-up wires 35 metres (average) distance apart, with double insulators.

40 kilometres length having a copper weight of 36 tons and 15 % loss.

Transformer Stations:—14, distributed over the length of the route, in stations, each provided with transformers of 150 kilowatts in ribbed boxes and immersed in oil, and without further cooling.

The transformer stations serve as towers for the wires and have forked lightning arresters with water resistances.

A special wagon is used for making repairs and conveying the transformers.

Rolling Stock:—2 electric locomotives with two axles coupled, 2 asynchronous motors 300 HP. and cog-wheel reduction.

Carriages for goods and passengers, total weight 28 tons, electrical equipment 10 tons.

6 automobile carriages, 4 axles, *i.e.*, with two bogies with two asynchronous motors together 240 HP., and 66 seats, total weight 32 tons, electrical equipment 8½ tons.

Locomotives and automobiles carry in front 2, and behind 2, contact bows to conduct the current to motors.

Locomotives and automobiles have the speed regulated by a variable resistance in the rotor circuit. They have small three-phase motors driving the air-compression plant of the Westinghouse brake. They can always be coupled to any carriages of the Swiss standard railway.

They contain small transformers and switches for electric lighting and electric heating.

DRIVING.

Single and double passenger trains consisting of two automobiles with carriages. Speed 36 kilometres per hour (single train 55 tons).

Goods trains with locomotives run at half-speed.

Steam engine in reserve.

ENGINEERS AND CONTRACTORS

of the whole electric plant and equipment: **Brown Boveri & Cie., Baden.**

Mr. Crompton (whose remarks were illustrated by lantern slides): I think the Institution as a whole is to be congratulated, not only on the Swiss visit, but on the very able report that the Committee has prepared on that visit. The report will be of extreme value, not only as a work of reference, on account of the statistics it contains, but becaus- Mr. Crompton.

Mr. Crompton.

it will definitely state for the benefit of those who come after us, exactly what was the state of the Swiss electrical engineering industry at the time of our visit.

The tour, as far as I was concerned, commenced at Basel. There the first object noticed was the electric tramway. The only thing that I can say in regard to that tramway is that, when it was first put down, a couple or three years ago, by Siemens & Halske, of Berlin, I was laid up in a house within twenty feet of the tramway, and then it was impressed upon me for the first time what a wonderful thing an electric tramway is: cars could pass at frequent intervals in front of a house where I was passing a sleepless night, and yet I was quite undisturbed. Except for the hissing noise of the bar along the wire, it was not possible to tell that the car was passing the house. This shows how electric tramways can be carried into a residential neighbourhood and yet be a far less disturbing influence than almost any other means of transit.

We next went to Rheinfelden, and visited the Power House, where we saw typical Swiss practice, almost the first development in which Swiss practice began to differ from our practice, which was forced upon them by the very frequent necessity of running dynamos on the vertical shaft of their turbines. The Swiss engineers began to undertake large work, and to put down (I think I am right in saying) almost the first large installations for electrolytic work which demanded large low-tension continuous-current dynamos. Mr. Brown, whilst at Oerlikon, commenced, and afterwards the Maschinenfabrik Oerlikon and others followed in the same lines, using the vertical type of dynamo to which we have been unaccustomed in this country, but which has become quite a common type in Switzerland.

I think the first point we noticed was that the Swiss engineers were not afraid of a rise of temperature which would appal the consulting engineers in this country. We noticed, when we opened the doors of the power houses, a puff of warm air, which was afterwards a familiar feature to us, and which we were led to believe was quite the right thing. It seemed wrong enough to us when we first entered these power houses, but we found out afterwards that it was practically right, as the machines are quite efficient enough, and have certainly not suffered from any deterioration of the insulation due to over-heating.

After leaving Rheinfelden, we went through Messrs. Brown, Boveri's works, and then proceeded to Zürich, and we were several days there. Throughout those days we had an opportunity of inspecting, at our leisure, the various great Swiss manufacturing electrical works—Oerlikon, Brown Boveri's, and Alioth's at Basel. The first works we went over were those of Messrs. Brown, Boveri. I take this opportunity of calling your attention to the history of Swiss electrical engineering. Switzerland is a country where coal is dear, where water supply is plentiful, and where, from the very first, some form of transmission of the power available in the water had been [illegible] At Schaffhausen there are various kinds of wire-rope trans[illegible] 1882, Messrs. Sulzer Brothers, as one of them

reminded me, ordered from me a pair of dynamo machines for the purpose of electrical transmission at this place, and I was exceedingly proud to find that this was the first electrical transmission in Switzerland. Sixty-five per cent. net efficiency was obtained, and that was considered so satisfactory that I believe I was the humble means of inducing a great many Swiss engineers to take the matter up. At all events, Mr. Charles Brown very shortly afterwards began to carry on work in the old machine-tool factory at Oerlikon, and very rapidly made his name and fame there. As you know, he afterwards moved on to his own works at Baden. Oerlikon then passed successively under the very skilful hands of Kolben and the Hubers. We also met another exceedingly good engineer in Bürgin's old partner, Alioth, at Basel. The advantage that these men enjoyed in having in their midst the style of workmanship and mechanical training available in the works of Messrs. Escher Wyss & Co., in the Winterthur Locomotive Works, and last, but not least, in the works of Messrs. Sulzer Brothers, the princes of good workmanship of the entire world, must never be forgotten. It has stamped Swiss electrical engineering with a record for finish and appearance such as is possessed by hardly any other class of electrical workmanship. I am sure that you could not wander through the shops there without admiring and wondering at it. I call your attention especially to the wonderful winding in Messrs. Brown, Boveri's shops. Every class of winding, whether it was winding that is dragged through the holes and pulled into position afterwards, which is the most difficult of all, whether it is the winding that is done on formers, or whether it was that beautiful bar copper, coiled on its edge and insulated with its split disks of paper—from beginning to end the winding in Brown, Boveri's place must have been a revelation to many of our English engineers. Moreover, the others are so nearly equal to them that I always say in my own works—and I believe all English engineers, if they are really truthful, say the same—that if the winding is as good as the Swiss winding, it is quite good enough as regards both the finish and the electrical requirements. As regards mechanical finish, our party had the advantage of having Messrs. Sulzer before them. Three or four of us had the privilege of spending a quiet and most interesting day in Messrs. Sulzer's works. I did not think it was possible that large engines, for months in the shop, could be finished without so much as a single scratch on them from beginning to end. It is inconceivable that in any English engineer's shop some apprentice or labourer would not have carelessly scratched beautiful cylinder lagging such as that we saw on the 1,000 H.P. engines. It does not seem possible with the highest discipline we have in our English shops to have attained to that perfection of cleanliness, neatness, and finish that we saw there. There is one thing consoling. Although they are very perfect, they demand and obtain high price. High-class work will always demand and bring high prices, and I think it will be a powerful incentive to us in our branch of the mechanical engineering trade to work up to the same pitch and always try to get the same finish and that equally high price. That is what I envy in Sulzers', that they have built up such a name for workmanship that they continue to get orders from all parts of the

Mr. Crompton.

world at these top prices, which is always the highest compliment to good workmanship that there can be.

I would call especial attention to the splendid Sulzer engines in the different power stations; whether the Swiss engineer couples his dynamo to the turbine or to the Sulzer type of engine he has been taught to believe that the highest development of steam machinery is the Sulzer engine and to build his dynamo to suit it. Consequently the Swiss dynamo is often designed in the form of a large fly-wheel dynamo, and so we begin to see the wide divergence between Swiss practice and ours. The Swiss had their Sulzer, we had our Willans; they thought out equally difficult problems in a different manner, and Sulzer and Willans have each in his own country profoundly influenced the early type of electrical engineering.

Other things have differentiated Swiss engineers from English engineers. Swiss engineers, beginning with a little lighting and a good deal of transmission of power, have had to utilise water power so much that they have become passed masters in the production of machinery for power transmission over great distances. The demand on English shops has been entirely different. In this darker, fog-laden, atmosphere the demand for light is very great, and the consequence is we are far more accustomed to lighting engineering than are the Swiss. Our shops have been filled with electric machinery suited to our requirements, suited to our stations, and suited, last but not least, to our wonderfully advanced high-speed engines. The result has shown itself practically in a wide differentiation in the kind of machinery we turn out. The transmission of power forced the Swiss engineers early to appreciate the enormous advantages of the alternating current, particularly in its multiphase form, and as a result you see their shops nearly filled with it. Hence, and I am sure Mr. Brown and others will agree to this, although the Swiss are ahead of us in that particular class of work, I do not think they can claim to be in advance or even to equal us in the production of our own class of machinery. The magnificent specimens which I have seen within the last few days, at Manchester for instance, of continuous-current dynamos of 2,500 H.P. certainly surpass anything we saw in Switzerland in that line. We cannot shut our eyes to the fact that we have not only maintained our position in that branch of work, but I think we have bettered it; and that is due to the difference between the conditions under which we have had to work. Consider what an advantage in one respect the Swiss engineers have reaped from the condition of things which forced them into high-pressure work. If electric railways—I do not mean tramways, but railways—are to be worked at all they are to be worked by high-pressure energy transformed. And what an easy thing it was for Swiss engineers to carry a little further what they had already done. I think none of you will disagree with me when I say that the great lesson we all of us learned there was the unexpected simplicity and satisfactory design of the railways direct-driven by multiphase currents. For example, if you were told that you were going to work a railway with two trolleys, a double trolley with a considerable potential difference between the two trolleys in the air, and return by the rails, you would have thought the

complication would be great. We were always told that a double-trolley system had been tried in America, and had failed on that account. Mr. Crompton

But looking at the Stansstad Railway, I think every one was astonished at the unexpected simplicity of the overhead construction, the switchboard, and of all the arrangements of this, which was the first railway of the kind that we saw. Everything goes to show that this multiphase railway working, instead of increasing the complication, is likely to decrease it.

I would call attention to a notice on one switchboard at the generating station of the Stansstad Engelberg Railway. It ran: "Erst besinne, Dann beginne." Many translations were suggested. One is *Think which, Then switch.*

With regard to photographs, no obstacle was put in our way; our amateur photographers might have taken snapshots of anything they pleased inside the works, but I think our members showed very good taste in not taking pictures of special tools or contrivances, or modes of manufacture. We only took the very special things we were asked to take, and I am very pleased that that was the case.

Mr. R. Hammond: We must all feel that Mr. Crompton has given us a splendid *résumé* of what we saw in Switzerland, and it is difficult to follow him, because he has been so exhaustive. Truly he says that Switzerland had before it a splendid example in the works of Messrs. Sulzer Brothers, and one cannot ponder too carefully upon this illustration of the way in which splendidly equipped engineering shops may influence the engineering of a whole nation. Another point that Mr. Crompton had not time to dwell upon, but in which I am sure he would perfectly agree, is that in the works of Messrs. Escher Wyss & Co., the makers of the turbine, you see the works of a firm which has been making turbines for generations. Some may think that this utilisation of water-power only began with the application of electricity to power-distribution, but it was most interesting in the works of Messrs. Escher Wyss & Co. to see pictures of the early turbines made by the progenitors of that firm for the utilisation of water-power one hundred years ago. They have really been learning their engineering not for one decade or two, but for a century; in fact they began, some say, in the century before last, but I would not like to introduce the "century" controversy at this late hour. At all events they can show you that the power-stations which they are now building all over Switzerland are the outcome of the labours of generations of engineers. Switzerland has had that great advantage, and Mr. Crompton says that that influenced the dynamo manufacturers to such an extent that they are turning out better dynamos than we are in England. There, sorry as I am to differ from him, I can hardly confirm him. It is certainly not compatible with the statement that there is a very large temperature-rise, that the dynamos are absolutely equal to those to which we are more accustomed, where the temperature-rise is smaller in consequence of the winding being better capable of carrying the current that is to pass through it. Speaking personally—and of course we are here only to give our personal opinions—the dynamo work did not strike me so Mr. Hammond.

Mr. Hammond.

much as the engineering work which we saw in Switzerland. I understand, however, that what we really have to do to-night is to see what lessons there were to be learned in Switzerland which we can bring back with us to England. In receiving the report and in recording our gratitude to those members of the Institution who inaugurated the idea of these visits to foreign countries, which have proved so valuable in the case of kindred societies, it is our duty to say that we feel that we have brought home some lessons which we can apply to engineering here. Unquestionably the chief thing that we saw was the utilisation of water-power, and it has been said that we cannot emulate the Swiss because we have not the water. I would like just to draw attention to the point which struck me on the first day. The first large works we visited were those at Rheinfelden, where we saw 16,000 H.P. obtained from water-power and being distributed, and the natural wish seemed to be that we had that water in England. It will be within the memory of some of the members who were at the luncheon afterwards, that it was pointed out, as I venture to point out here to-night, that though it be true that we have not the water in England, we have the coal, and it is not the actual turning-force of the dynamo which constitutes the whole of the cost of electrical energy.

There is a feeling among the public that, by means of water-power, electricity might be made much cheaper to the consumer; in fact it was stated in a communication to one of the technical papers that, by means of water-power, they were enabled in Switzerland to sell electricity at a profit for ¼d. per unit. One characteristic of the Swiss visit was, that we did not get informed upon many commercial points. If a similar tour had been made through England, the tourists, if one might so call them, would have been deluged with statements as to the cost per unit delivered to the consumer, the percentage of cost to revenue, and revenue per unit delivered to consumer, and all those cabalistic figures which so many delight in. We passed through Switzerland, I believe, without knowing what was the cost per unit anywhere, but some would have been happier if we had been able to ascertain this. One of us ventured to inquire in the first works visited, but did not succeed in finding anybody who would give any information thereon. I gathered from this, that in Switzerland, the engineer concerned himself with engineering, and looked upon the commercial part of the business as something which was rather the province of the commercial man. Of course, as one acquainted with many consulting engineers in this country, I was pleased to find that the engineer in Switzerland had so important a position. Some have come back from Switzerland considering that the real moral of the trip was that consulting engineers were apparently unnecessary and were absolutely ignored in that country. I did not form that idea. At the very first works we went to we found that not only was there a consulting engineer, but that he was resident. In this country it is the unfortunate practice to force the consulting engineer to consult for many places, and to shift him about by train and boat from one place to the other, until, if he attends an Institution meeting he has to catch the newspaper train in order to get to the north of Yorkshire the next day.

Mr. Hammond.

At the lunch at Rheinfelden one of the toasts was replied to by Dr. Frey, a most eminent engineer, who acted as consulting engineer for the great works at that place. He is one of the great type of consulting engineers, the one with due regard to the position of the manufacturer, who considers that it is the duty of a consulting engineer to step in between the buyer and the seller, and enable the buyer to spend his money to the best advantage, and to treat the manufacturers' standard patterns as something that he must give encouragement to. There, on the threshold, we found such a man in Dr. Frey. And we found throughout our trip, those of us who were interested from the consulting engineer's point of view, that they were responsible for the work.

Finally, to return to the question of water-power. Though we have not the water-power here, we have something which takes its place, and which forms a certain proportion of the cost of generating electricity. I have inquired into the proportion which the cost of coal bears to the total cost of production in the United Kingdom. I find that (for example) in Kensington, the cost of coal is 25 per cent. of the total costs, including works'- and management-costs, and in fact all those which we find classed by the Board of Trade as costs of production and distribution. Therefore if the coal bill were abolished, the total cost at Kensington being 3·04d. per unit, would be reduced by only ¾d. It is very absurd, therefore, to say that by merely substituting water for coal you will reduce the cost from 3d. per unit to ¾d. The utmost you can attempt to do is to eliminate the coal bill entirely. But of course in substituting water for coal you put in something which also entails expense. I need not detail what, for you are well acquainted with it. I might equally well have taken any station other than Kensington as an example. At Leeds the coal bill is only 17 per cent. of the total costs. The real lesson to be learned by the application of water-power is not the substitution of water for coal, but that aggregation of load is the real element in low costs.

Mr. Swallow.

Mr. M. G. S. Swallow: As a member of the profession and of the Institution who has been for some years in Switzerland, I wish to thank both Mr. Crompton and the members generally for the great interest they take in Swiss electrical engineering. I had not the good fortune to be with the members of the Institution during the whole of the visit, but one of the most interesting plants which they saw was no doubt the Burgdorf-Thun Railway. I have been very interested in comparing the manner of working railways electrically in England and on our Swiss lines. I have to-day had an opportunity of seeing some part of the plant of the Central London Railway, and was rather astonished to find that the three-phase current, which is used principally for transmission, is not employed directly to propel the trains. No doubt there are very urgent reasons why this should not be the case, but three-phase driving is practised on the Burgdorf-Thun Railway, and I think it fulfils all the requirements of that railway, and will continue to do so even when the railway shall have a large traffic to arrange for.

Professor Carus-Wilson.

Professor C. A. Carus-Wilson: Those of us who had the benefit of Mr. Swallow's guidance in going over the Burgdorf-Thun Railway, of which he is the resident engineer, will appreciate his remarks in con-

Professor Carus-Wilson.

nection with the relation between electrical railway enterprise in England and three-phase railway enterprise as now conducted in Switzerland. It must indeed be astonishing to railway engineers coming from Switzerland to visit our Central London Railway, to see the three-phase generating plant, with continuous-current motors on the locomotives. The impression conveyed to the majority of the members in Switzerland must have been that the Burgdorf-Thun Railway was the most remarkable thing we saw. It is especially remarkable because the people who were interested in putting down this railway knew very well the undertaking was a critical one. Most of the members must be acquainted with the peculiar conditions which render the railway quite a unique electrical undertaking; it is a normal-gauge railway, linked with all the other Swiss railways and carrying ordinary traffic; in fact, it is, in every respect, a standard normal-gauge railway. That the promoters of this enterprise should have undertaken to equip it with three-phase motors is the greatest proof that we can have of the confidence that the leading engineering firms in Switzerland have in the application of the three-phase system to railways. I think it cannot be a matter of doubt that although the financial success of the Burgdorf-Thun Railway is yet to be proved, if there had been any question as to the comparative efficiency and economy between the three-phase and the continuous-current systems, those who were responsible for equipping that railway would not have used the three-phase system.

We had many striking and interesting illustrations of three-phase railway practice, not only in the Burgdorf-Thun Railway but in other electric railways which we visited in Switzerland. We were able to make useful comparisons of present Swiss practice in the locomotives made for the Jungfrau Railway by the two great engineering firms, the Maschinenfabrik Oerlikon, and Brown, Boveri & Co. I noted several points of difference showing that the locomotives made by the Oerlikon Company differed in many important respects from those made by Brown, Boveri & Co. In the first place the Oerlikon locomotives were 19 tons against Brown, Boveri's 13 tons. Brown, Boveri's motors had fewer poles than those from Oerlikon, and the gearing was cut very differently. One of the most interesting electrical differences between the two types of locomotive was that the Oerlikon firm used different rheostats for the two rotor resistances, while Brown, Boveri used the same rheostat. The latter method has a very peculiar effect, which may have been observed by the members who travelled on the Jungfrau Railway. I allude to a jerking motion, especially at the moment of starting. This is in consequence of the fact that the two motors on the locomotives are coupled in parallel on to the same rotor rheostat and produce a hunting effect, which gives this peculiar jerk in mounting the incline. The Oerlikon firm avoids the effect by having separate rotor rheostats.

One of the most common objections raised against polyphase motors for railway work is the very small clearance that you are obliged to work with. It must have astonished mechanical engineers when they ned how exceedingly narrow the clearance was in the motors on all hase electric railways. For instance, on the Burgdorf-

Professor Carus-Wilson.

Thun Railway the clearance between the rotors and the stators was only 1½ mm. on the radius, and they were running at 600 revolutions a minute. Swiss engineers have tried even narrower clearances. I was told that they had at first tried a clearance of ½ mm., but had been obliged to enlarge it little by little until at last they increased it to 1½ mm., and they were quite satisfied with that.

Mr. Crompton has already alluded to the question of overhead conductors. That is another objection which is constantly raised against three-phase work. But it should be borne in mind that all the Swiss railways have level crossings, and consequently are not able to have auxiliary third rails. I understand that if they were working under British conditions with crossings under or over the permanent way, they would use auxiliary rails, and do away with overhead wires altogether.

Those who travelled over the Burgdorf-Thun Railway must have been struck with the simplicity of its construction; in fact the three-phase motor seems to lend itself in a remarkable way not only to the class of work it is put to in mountain railways, but for the ordinary traffic of ordinary steam railways. One great advantage is no doubt the uniform rate of running, which depends upon frequency and not upon load. The Burgdorf-Thun Railway has a drop of only 2 per cent. at full load, and the speed is kept constant within those limits. Then there is perfect regulation of speed by the rotor resistances, and a perfect variation through the extreme limits of speed and load can be obtained.

Of all the interesting things we saw on these three-phase railways, I think the most interesting was the Engelberg train coming down a 25 per cent. gradient held by nothing whatever but the current returned into the line from the three-phase motors acting as generators. That is a thing few of us had seen before. I ascertained definitely from the engineer, that in descending the 25 per cent. gradient the whole train was thus held, and descended with a speed only 5 per cent. greater than the normal speed of synchronism without any brakes. This is a great achievement, and I think is one of the most remarkable features of three-phase railway work.

Mr. Birks.

Mr. L. BIRKS: Though not included in the Institution visits, a few slides and details of the Hagneck Water-power Station may not be devoid of interest. Those of the party who were at Baden will remember the large alternators for this plant which were being erected in the shops of Messrs. Brown, Boveri. I am indebted for the following details to Herr G. Kölliker, the resident engineer for the Elektricitätswerke, Hagneck, who kindly showed me over the plant. Hagneck is a small village on the east shore of the Lake of Bienne, some seven miles from Bienne itself, the nearest town of importance. The power is derived from the Hagneck Canal—a large watercourse constructed some years back to drain off the surplus water of the Aar to the lake. The works necessary to utilise this power were commenced some two years ago, and are now approaching completion. By throwing a weir across the mouth of the canal a fall of six to nine metres is obtained. The pressure on the four piers at high water will amount to 130,000 tons. From above the weir a short canal 100 metres long by 27 metres

Mr. Bird.

broad leads direct to the turbine-house, whence a short tail-race carries the water to the lake. The hydraulic plant consists of five "four-story" Jonval turbines of 1,350 h.p. each by Messrs. Bell and Co., of Kriens. These run at a speed of 200 revolutions per minute. Each turbine-chamber is closed above by two rotating gates actuated by a separate 25 h.p. turbine, allowing regulation by hand. Automatic regulation is also provided for by altering the inclination of the turbine guide-blades. The three-phase 8,000-volt alternators are mounted direct on the vertical turbine-shafts. Their exciters are driven from the same shaft by bevel wheels, and are themselves excited from a secondary exciter, driven independently by a 20 h.p. turbine, of which one is always in reserve. This arrangement reduces variation in voltage of the exciters due to variations in speed of the turbines. As at the Kanderwerk, the load is divided between two separate distributing circuits, the "ruhig" and "unruhig"—the steady and variable load: lighting and small motors will be connected to the former, large motors and tramways to the latter. The power is distributed direct on an overhead pole line at 8,000 volts. Of the 5,000 k.w. generated, 2,000 will be taken by a calcium carbide factory at Nidau, nine kilometres distant. The remainder will be distributed over an area of 55 kilometres diameter, including some fifty small villages and several large towns.

Mr. Robinson.

Mr. MARK ROBINSON: Though I was not able to go to Switzerland with the Institution, I should like to join with Mr. Crompton in his tribute to the good work of the Swiss, and in particular to the splendid work done by the firm of Sulzer Brothers. Some three or four weeks ago I visited Messrs. Sulzer's works, and enjoyed the privilege of thoroughly inspecting the works under the guidance of Mr. Carl Sulzer. Certainly they deserve everything which Mr. Crompton has said of them, though I do not altogether like the praise he gave to the absence of scratches upon the external finish; praise is better deserved by the magnificent accuracy of the work. This is doubly deserving of praise because they do not work under the favourable conditions which prevail in some few works (though unhappily only a few) in England, where everything is done to gauge and template. They do not work on that system, and they lament a great deal that they do not and, as they think, cannot. It would be much better for them if they could. But without it they obtain an accuracy which, although I do not think it is greater than ours in England, is at any rate as good. What struck me most in Switzerland was not the mere fact that they have water available there, because I agree with Mr. Hammond that it makes comparatively little difference financially whether there is water available, or whether steam has to be used: what strikes one is the great development of three-phase work. It seemed to me that those gentlemen who understand the electrical side of the matter much better than I do would benefit us by turning their attention to three-phase work, and seeing whether its immense development in Switzerland might not be repeated here.

Mr. Raworth.

Mr. J. S. RAWORTH: Mr. Crompton never speaks without giving this Institution the greatest pleasure, and I feel that all of us will feel some

trepidation in hearing that he is thinking of leading our noble and brave brethren at the Cape. I want to make one suggestion which has nothing to do with Switzerland, and that is that he should impress upon the members of the Institution that the funds he is collecting are to be used in making our friends in the Electrical Engineers' Volunteer Corps more comfortable when they are out at the Cape, because I know that some people to whom the appeal has been addressed have thought that the finding of plant ought to be done by the Government, and therefore they have not responded so heartily as they would have done if they had known to what purpose it was intended to apply the funds. Mr. Raworth

I have not very much to say about Switzerland. I can only say that the pictures on the screen were so lifelike that when we came to one place I felt hungry, and in another place I felt thirsty, and in another place I felt in a great perspiration. I can assure Professor Carus-Wilson that if I had known when we were coming down the Engelberg railway that we were only held up by the motors acting as generators, I should have been in the greatest perspiration of my life. Mr. Crompton says that our manners were excellent, and if we did not go about photographing things it was simply because we ought not to have photographed them. I can go a step further, and say that as far as any words which I heard spoken by the English electrical engineers in Switzerland are concerned, you would have thought that they had done nothing at all; that they had not come from an electrical country; and that there were no great electrical works in this country. They were consumed with telling our Swiss hosts what excellent work they did, and how charmed they were to see so many developments there which we had not at home. This was entirely correct, because the things we saw there were all of a special character, of which we have had very little or no development in this country. But if ever it should fall to our lot to entertain our Swiss hosts in this country, I am quite sure they will be willing to pay a like tribute to the progress of electricity in England, and they will be able to see some works which will astonish them. I am quite sure that if they will only come here they will not be let off with any less hospitality than they provided for us. The matter of what we saw there was pretty well thrashed out some time ago in *Lightning*. Everybody was asked to send in his views as to what he had seen, and although a good many of us treated it lightly, there were one or two who entered into the matter at great length. This Report gives the details of most of the experiences which we had. The Committee have done their work very well indeed, but I should like to suggest to the Committee that they have omitted one thing in the third paragraph. They say: "At Rheinfelden, after visiting the power station, the members were most hospitably entertained at lunch by the directors of the Kraftübertragungswerke." They do not say that Herr Rathenau came all the way from Berlin in order to be present at that luncheon, and to give us a very warm and hearty invitation to go to Berlin another year, which invitation I hope the Institution will have the opportunity of accepting.

The President
The PRESIDENT: It is accepted.

Mr. J. SWINBURNE: I am one of the few unfortunates who were Mr. S[illegible]

Mr. Swinburne.

unable to go to Switzerland with the Institution. I have, however, been in that country, and for professional reasons I have been over a good many of the works in France, Germany, and America, so that I may make a few remarks with regard to the various differences in practice. We need not attempt mere admiration or mere criticism, but I should like to discuss some of the differences between British and Continental practice, and, if possible, some of the causes of difference. I daresay you noticed that in going into an engineer's office, you generally see a pile of journals. They are not only Swiss journals, but you will notice every journal you have ever heard of, and a great many that you have not. The Continental engineer is an omnivorous reader; he knows everything that is going on in every other country, just as well as he does what is going on in his own. In England I am afraid we do not do that. We have worked rather on another system. In early days, you will remember, when electric lighting came forward, each person had some system which included a dynamo, a lamp, and everything else, all supposed to be of his own invention, and probably all equally bad. Then we got into a state in which every maker made either a Tom dynamo or a Dick dynamo or a Harry dynamo. If Tom had a dynamo which had the armature at the bottom, Dick put the armature at the top and stuck his name on it. That inventive ambition has been most disastrous. Every one tried to have something called after his own name. All over the Continent there is a general tendency towards uniformity of practice, and that I think is largely due to the fact that engineers as a rule are not keen about introducing their own particular inventions, and having things called after their own names. The plant is generally known by the name of the firm only, and the engineers are simply anxious to have the best thing that they can, whether it is their own invention or not. That sort of system may tend away from originality, and probably on the Continent there is less originality in invention than in England, but as the foreign engineer can see the inventions of everybody else, he has an opportunity of combining all the best ideas of every nation, so that he naturally gets very good machinery. That, I think, is one reason why both the Germans and the Swiss have gone ahead of us, I do not say generally, but in many ways. Another departure from our practice which is displayed abroad is that they generally sacrifice electrical efficiency to cheapness and mechanical strength. Now mechanical strength is not necessarily opposed to electrical efficiency, but I think if you investigate the electrical and mechanical efficiency of many of the dynamos on the Continent, you will find them so far behind that, if you could really know and work out the extra cost of running them, you would find that they were very expensive machines indeed in the long run, but that they do not often break down.

Another fundamental difference is not perhaps electrical, but commercial. You will see it throughout the Continent, but especially, perhaps, in Germany. In England the owner of a works considers it a nasty thing which must be put into some dirty corner of the town where it will be among smoke and surrounded with mud, and so on. He looks upon the works simply as something which brings him in so

much a year. He takes no workman's pride in his works; he does not care whether they look nice or not. That perhaps is not so much the case with regard to electrical engineering in England as it is in other branches of manufacture. Now, on the Continent, you notice that the owner's, or at any rate the manager's, house is probably on the works. The whole place is beautifully kept and quite clean, and probably in the yard you will find a garden and a fountain playing. That may seem a little exaggerated to us, but the same principle is carried right throughout the works. I have been over a great many works in Germany and Switzerland, and I have only seen one equal to ours in dirtiness and untidiness. In America also there is a perfect system of order and cleanliness. It is not only a matter of expense; it means that if you keep the works perfectly clean and tidy, and have everything comfortable, the men will take a pride in their work, and do it better, and feel more interest in it, and are not so anxious to get home. Mr. Swinburne.

Another difference we ought to remember is that the Trades Unions in most of the countries are not so strong as they are here. I have employed both French and American workmen, and in both cases I found they were broadly divided into very different classes, one was very unintelligent, and the other very sharp, able men, who were really scientific people as well as workmen. We do not get that sort of distinction here. The Trades Unions tend to level down all our workmen; the old millwrights were something like the superior class of Continental workmen, but now there is nothing like this latter class here. Then there is another point which influences things very much, and that is the law of electric lighting in this country and abroad. I do not know very much about the Continental laws, but the general principle is, I think, that the local authorities give concessions over a certain number of years, and the industry is less hampered.

The question of finance is also different. Enterprises in Germany, for example, are generally financed in a way which is quite unusual in England, namely, by Banks. We look upon a Bank in England as a place where you put so much money for drawing cheques, which are more convenient than Post Office orders; but a Bank abroad is a speculative concern, which supports enterprises. It does not lend money only on mortgages and so on, but it takes up industrial enterprises. The Limited Company does not flourish to the same extent, but the Bank, with solid advisers at its back, makes a very much sounder means of carrying out industrial enterprises. That is a system that we want very much.

Another thing about Continental works which is very important is the difference in the way of developing. Some bacteria and other organisms, as we know, multiply by fission. You will find that the Continental works do the same. Messrs. Siemens, for instance, have a works in England which is a branch of Siemens & Halske. You will find that Siemens & Halske have started works in Germany and in other places one after the other. Ganz have done the same thing exactly, as at Schneiders and Helios, and they do a great deal of work in particular countries, such as Italy. The Allgemeine and Brown, Boveri in the same way have manufacturing places in different countries, and

Mr. Swinburne.

they gradually spread in that way. That is a course which we do not pursue in England, but it is one we ought to pursue, especially as we have generally more chance of getting capital in this country than they have abroad.

Finally, I would like to protest against expressions of astonishment at a railway running down hill with a motor. I think it shows an absolute want of grasp of the nature of electrical appliances to utter such a sentiment as that. If a motor has sufficient torque to pull you up a hill, surely it has sufficient torque to take up the less power in going down hill. A magnetic pull is as real as the pull of a bar of metal.

Mr. Sellon.

Mr. R. P. SELLON: I beg to move that the discussion be now adjourned to the next meeting of the Institution, as there are probably many here who would like the discussion to be continued for another evening.

The resolution was agreed to.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Member:

Timothy Howard.

Associate Members:

Matthew Atkinson Adam.
Frederick Black.
John Carlos Calastremé.
John Edward Donoghue.
Seton George Legge Eustace.
Heber Davie Evans.
Herbert Henry Edward Heath.
William James Adam Edward Horne.
Henry Robert Low.
Frank Pickering.
Percy W. Sankey.
Harry Snowdon.
George Senior Wallace.
John William Francis Warren.
Harold Babington Whitmee.
James Ashe Windham.
William Richard Wynne.

Foreign Members:

Francis Bacon Crocker.
Antonio De La Mora.

Associates:

Hubert George Alder.
William Robb Barclay.
Joseph Beattie.
Douglas Constantine Behrends.
Alfred Sydney Blundell.
James Brown.
Sydney Dale.
David Gill, C.B., F.R.S.
Harold Griffiths.
Alfred Richard Hakoumoff.
Ernst Olaf Henrici.
Henry Hercules Hodd.
John Frederick Wood Hooper.
William George Hull.
George Gilbert Jobbins.
John Thompson Mertens.
T. F. Santonna.
Cromwell John Ernest Walker.
Lancelot William Wild.
John Moseley Williams.
Norman Charles Woodfin.

Students:

Charles Francis Anderson.
Richard Platt Avens.
John Alfred Ballard.
Arnold William Bartlett.
Frederic Charles Baumann.
John Dutton Billington.
George J. Bish.
Richard Ponsonby Blennerhassett.
Benjamin Ewart Briggs.
Gomer Bertram Davies.
Leslie Herbert Davies.
Herbert Charles Dear.
William Allwood Dutton.
Clement L. Faunthorpe.
Robert Fisher.
William Alfred Fitzgerald.
Harold Frodsham.
Thomas Garnett.
John Alfred Gilfillan.
Hubbert Arnold Green.
Henry Henshaw Bailey Grundy.
Ernest Charles Handcock.
Lionel James Burstall Hannan.
Fielder J. Hiss, Jun.
George Hedley Hunt.
Walter John Jeffery.
Bernard Cyril Johnson.
Charles Richard Kemp.
Ewen McKinnon Kerr.
Alec Arthur Kift.
Thomas Henry Langford.
Philip Alfred Laubach.
Arthur Henry Lawrence.
Edward Lea.
Edward Stephen Luyks.
Brian Harold Morphy.
Hugh Fletcher Moulton.
Leonard Murphy.
Malcolm Parker.
Richard Lloyd Pearson.
Fred Pritchard.
Frederick Robert Charles Rouse.
Grout Benjamin Dickson Croft Saw.
Harry Seward.
James Edmund Starkie.
Carl Percival Hugosson Tamm.
Frank Tidman.
Theophilus Henry Vigor.
Percy Webberley.
Piers Acton Eliot Warburton.
William Sydney Wright.

The Three Hundred and Fortieth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 25th, 1900, Professor SILVANUS P. THOMPSON, F.R.S., President, in the Chair.

The PRESIDENT: Gentlemen, before the minutes are read, we have a very sorrowful duty thrust upon us by the sad loss which the Institution has sustained in the death of its Past-President, Professor Hughes. In making this announcement formally from the chair, I feel a very deep sense of personal loss in the removal of one whom I have known for so long, who had the interests of this Institution so thoroughly at heart, who never missed a Council Meeting if he could help; one who was continually with us, and was himself a very earnest and sincere worker, interested in all our proceedings. I need not recount the many claims upon us that are indissolubly associated with the name of Professor Hughes. His fame as an electrician is world-wide. His career began, more than thirty years ago, with the invention of the printing telegraph, which brought him into relations with the Postal departments of every civilised country, which brought him recognition as a scientific man, and which also brought him official recognition and official honours from every Government in Europe, except only from that of this country. His success with the type-printing telegraph was followed afterwards by those remarkable researches of his which led him to the invention of the microphone, and, after the microphone, of the sonometer and the induction balance; and after the induction balance the magnetic balance, and then still later that piece of work which remained for so long unknown, when he succeeded in sending over more than 200 yards definite signals without any wires, by a process which we have every reason to believe is practically identical with that followed in the more recently discovered wireless telegraphy. These achievements of Professor Hughes placed him in the first rank of pioneers in electrical work. He was our President, and as President some thirteen years ago he gave us a very remarkable address, which had the effect of producing a number of researches on the subject of self-

induction which greatly advanced our knowledge of that subject. It was, perhaps, one of the most remarkable presidential addresses to which we have ever listened. Since then he read a paper to us on the use of oil in insulation, and he occasionally took part in the discussions in this room. We never listened to him without feeling that he had something to say, and that whatever he had to say was worth hearing. Those of us—and there are many of us—who enjoyed his personal acquaintance and friendship know what a very true-hearted friend he was. I therefore, with this deep consciousness that we have lost one with whom it will ever have been an honour to be associated, move that a vote of condolence and sympathy with Mrs. Hughes be passed by this meeting.

"That this meeting of the Institution of Electrical Engineers hereby expresses its deep sense of the loss sustained in the decease of its Past-President, Professor D. E. Hughes, F.R.S., and tenders to Mrs. Hughes the expression of its condolence and its most sincere sympathy."

Major-General WEBBER: A very conspicuous figure and a very distinguished member of this Institution has, as you know, disappeared in the last few days from our ranks. Some of us remember him for many years as sitting at this table, and as speaking to us and giving to us the results of his experience in connection with his many inventions. I remember an incident in his life when he and I were at Berlin together in 1866. (I was at the time examining the system at the central telegraph station there), and he was also in daily attendance, making experiments with, and teaching the staff at Berlin, the use of his type-printing telegraph. I well remember, when finally it was passed on behalf of the Prussian Government by General Von Chauven, the Director of Telegraphs, when Professor Hughes (he was then Mr. Hughes) was paid in cash a very large sum for his Prussian patent, he opened a hand-bag and showed it to me, as he left the offices of the State Telegraph Administration. I believe it was then he received the most valuable encouragement that he ever had as an inventor, and laid the foundation for the large fortune which afterwards enabled him to give his time to research.

I beg to second the motion which our President has brought before us, that a vote of condolence and sympathy

on the occasion of her sad loss, be passed by this meeting and be sent to Mrs. Hughes.

The resolution was put and carried, all the members rising in their places.

The PRESIDENT : I have a letter from the executors of the late Professor Hughes, dated to-day, stating the arrangements made for the funeral : "The funeral of the late Prof. D. E. Hughes, F.R.S., etc., will take place on Saturday next, the 27th inst., at Highgate Cemetery at noon." "A special service will be held in All Souls' Church, Langham Place, close to the Langham Hotel, at the top of Regent Street, at 10.45 o'clock on Saturday morning, at which we hope yourself or some other representative of your Society may be present." I may add that the Council has, at its meeting just held downstairs, arranged to be officially represented both at the service at All Souls' Church at 10.45 and at the ceremony of the funeral at noon in the Highgate Cemetery. We understand that it will be a gratification to Mrs. Hughes if all or any of those present, who knew Professor Hughes, were able to attend either the ceremony in the church or the interment at the cemetery.

The minutes of the Ordinary General Meeting held on January 11th, 1900, were read and approved.

The names of new candidates for election into the Institution were announced, and ordered to be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Charles Frederic Heywood.

From the class of Associates to that of Associate Members—

Charles Claremont Atchison.	Alfred H. Irvine Graham.
Thomas P. E. Butt.	Frank Hewer.
John George Freeman.	Arthur Maitland Keays.

From the class of Students to that of Associates—

Wilfred Birks Cleeves.

Messrs. Norman Smith and H. D. Hodges were appointed scrutineers of the ballot for the election of new members.

The SECRETARY read the following list of Officers and Committees which had been elected by the new local sections in Dublin and Glasgow respectively :—

OFFICERS AND COMMITTEE OF THE DUBLIN LOCAL SECTION.

Chairman—Professor G. F. Fitzgerald, F.R.S.
Vice-Chairman—Colonel C. F. C. Beresford, R.E.

Committee.

Professor W. F. Barrett.	G. F. Pilditch.
C. P. C. Cummins.	A. E. Porte.
R. Humphries.	M. Ruddle.
M. C. Olsson.	P. S. Sheardown.

Hon. Secretary—F. Gill.

OFFICERS AND COMMITTEE OF THE GLASGOW LOCAL SECTION.

Chairman—The Rt. Hon. Lord Kelvin, G.C.V.O., F.R.S.
Vice-Chairman—Professor Magnus Maclean, D.Sc.

Committee.

W. A. Chamen.	J. M. M. Munro.
Professor A. Jamieson.	W. B. Sayers.
W. W. Lachie.	F. Teague.
H. A. Mavor.	T. Young.

Hon Secretary—Professor W. H. Watkinson.

The PRESIDENT : We will now resume the discussion on the Report of the Swiss Visit Committee.

Mr. S. Z. DE FERRANTI : The principal thing that struck me with regard to the Swiss visit was the great facility for doing all sorts of electrical work on a large scale in Switzerland. It was not merely the fact of their having water-power available, but the customs of the country seemed to enable the people, or groups of people, to carry out without too much obstruction very considerable works, most beneficial to the country and to the development of the electrical industry. This struck me more than the installations which we saw, and it made me very much regret that we did not in this country seem to have that desire for something new and for going forward and testing on a practical scale Mr. Ferranti.

Mr. Ferranti. all the advantages of a great electrical business in the way in which the smaller country of Switzerland seemed to do. The tendency seemed to be for everybody there to help everybody else to advance in the great industry: and even more striking than this was the contrast between that and the terrible obstruction with which anything new in this country is met. There are so many vested interests, there are so many people whom it is the business of the whole country to protect, that the country at large suffers very much. The result is that we are in the unfortunate position of seeing Switzerland in many ways far better developed in the new electrical business than we are at home. We have almost unlimited quantities of very cheap coal, and many good supplies of gas: in fact, a good gas supply to almost every centre of population in the country. They, on the other hand, have dear coal, and plentiful water-power which is easily developed in many, but not in all, cases. I do not see that this puts us at any very great disadvantage. The fault in this country is the general obstruction to anything new.

With regard to some of the details of the work that we saw in Switzerland, I was very much impressed with some of the central stations. Take that admirable power-house at Spiez for running the Burgdorf-Thun Railway. The generating part of the work with turbines and multiphase dynamos was as good as it was possible to be; but the switching arrangements seemed to me to be exceedingly complicated. The mere handling of machines and the switching and regulation were in themselves a very big problem; but in addition to these, there were the step-up transformers and all the connections of the lines and the arrangements for securing safety and working the system generally. The greatest defect attached to the system which we saw there was, to my mind, the complication involved in the apparatus connected with it. A few days ago, at Manchester, I called attention to the very great expense and complication involved in such an installation as that at Glasgow, where, in order to save copper and get the advantages of the multiphase system for supplying the tramways all over the town, an immense amount of complicated apparatus had to be used. I do not say that it is altogether bad, but that, at present, all these appendages to the main part of the system are exceedingly costly, and that the direction for improvement, so far as one can see, lies principally in the simplification of these appendages. The idea is good, and the results achieved are excellent, but there is unfortunately an intermediate stage which is very costly and complicated, and if it is possible to reduce the complication and the expense and simplify the matter greatly we shall be in a much better position from the point of view of electrical distribution over large areas.

Mr. Kilburn Scott. Mr. E. KILBURN SCOTT: The first locomotives put into use on the Jungfrau railway were built at the famous Winterthur Works and equipped electrically by Messrs. Brown, Boveri & Co. Each locomotive has two motors, each giving 150 h.p. at 760 revolutions. There is one resistance for the two motors, current being collected by four trolley poles.

The Oerlikon Company have recently supplied three more locomo-

tives of greater power, each of the motors giving 200 h.p. at 550 revolutions. Current is collected by two grooved slides contact similar to those generally used in crane work. In the centre of each driving axle is the rack pinion having teeth 4 in. pitch and 2⅜ in. broad. These pinions are of aluminium bronze, and, forming an extension on either side, are two grooved brake-wheels on which work eight toothed clamps, the latter being actuated by two handles (one for each driver). A water reservoir is provided, from which pipes are taken down to the grooved brakes for the purpose of cooling them. There is also a tachometer to indicate to the drivers the speed of the motor shaft. The total weight of the locomotive complete is 17 tons, or 5 tons heavier than the first locomotives; of this, each motor weighs about 2 tons, and the cover 1¼ tons. Half the weight of the passenger-car rests on the locomotive, to obtain greater adhesion and give safety in working. There are separate resistances for each motor, and it may be noted that at present they are used not only for starting, but also for absorbing current when the locomotive is on the descent. The motors are always left in circuit so as to secure the automatic braking action, and any extra current is taken by the resistance, thus giving the generators a nearly even load. When there is sufficient traffic on the line the descending locomotives will pump back current to the line and so help the ascending cars. At present this is not quite feasible because of the irregular traffic, there being sometimes a locomotive descending whilst the one going up is standing at a station. It may be mentioned that on the 25 per cent. grade the locomotive will start of itself without current. For cooling the resistance wire a ¾ horse-power motor is coupled to a fan immediately below the coils. Mr. Kilburn Scott.

When the locomotive is exactly between the two transformer stations (which are 2,000 or 1,000 metres apart, according as the gradient is 12½ per cent. or 25 per cent.) there is a drop of about 12 per cent. in the voltage. The locomotive is then obtaining half its current from the one and half from the other station, whilst the voltmeter registers the lowest voltage obtainable. As the locomotive leaves this position the volts on the voltmeter rise gradually in proportion to the distance of the locomotive to the transformer, and by this means the driver can tell almost exactly the distance of his locomotive from the nearest station, independently of any landmarks or signals. If on passing the centre point between two sub-stations the loss increases above 12½ per cent., the driver at once knows that something is wrong or that the second locomotive is on the same section. The system therefore constitutes a perfect block system, and this appears to the speaker to be strong argument in favour of working the railways by sub-stations fitted with cheap static transformers fairly close together instead of larger sub-stations with rotating machinery at long intervals.

There are, of course, the hand automatic and electric brakes, as required by the Swiss regulations for working mountain railways, but independently of these special brakes the simplicity of the gear and connections is very striking. This can be at once seen by comparing a diagram of the connections of a three-phase locomotive with an ordinary car wiring diagram as required for continuous-current motors.

... Simplon Railway Commis- ... engineers, Messrs. Vest-Kunz and Thor- ... whether to employ three-phase ... converter sub-stations and continuous- ... whether to employ three-phase ... because of the greater ... regulating arrangements; *second*, because ... *third*, because of the ... sub-stations in which there would ... each other periodically; ... estimates had been prepared from ... that the first cost of the rotary ... greater than that of a ... employed.

... sufficient ... Surely the ... electric light and ... the contrary. ... per unit, and ... which the Swiss bring ... We have far too many ...

... expressed his surprise at the ... the Swiss three-phase ... showing the stirrup-shaped ... for the benefit of those ... which is effected ... trolleys at branches and ...

... overhead lines as sometimes ...

... with the rails, form the three ... current from the trolley wire, t_1, passes ... stirrup-shaped collecting shoe, and from ... other side of the stirrup. At the ... ends being supported ... span wire construction in the ... suspension ... is connected to t_4, and t_3 to t_2, the ... being arranged on the upper side so as not to interfere ... passes below. The main point to guard against ... passing the junction does not short-circuit t_2 and ... show successive positions of the stirrup as the car ... examination of the figure it is obvious that it is ... arrangement to avoid all possibility of short circuits ... position 5 it is clear that the stirrup is only ... overhead wire (either t_2 or t_3) the current ... motor is being supplied with single-phase currents ... running as a single-phaser. Owing to the ... would not start as a single-phaser, this cannot be ... therefore, the car is provided with two stirrups, so that

the hinder stirrup collects three-phase currents while the front one is passing over the junction, and *vice versâ*. Any one familiar with the perverseness of trolleys will recognise the disadvantage of employing four trolleys for such a crossing, with their inevitable tendency to jump the track at the frogs, and the great simplification of the split stirrup, which, if properly arranged, cannot cause short circuits, and in fact works very well. When the car reverses the stirrups automatically reverse, by raising the trolley and span wires until they have assumed a vertical position, and then dropping over into the reverse position. Mr. Field.

Some engineers, after visiting Switzerland, are, I think, too apt to jump to the conclusion that many of the English railways, such as the Dublin, Middlesbrough, and Central London, where the distribution of power to different parts of the line is effected by three-phase high-tension currents, might have been better equipped with three-phase

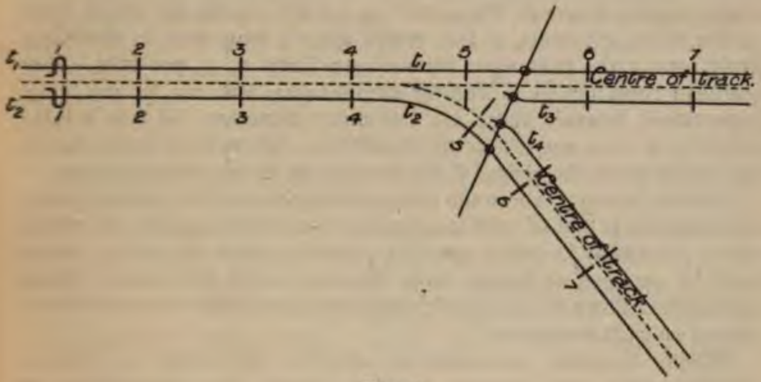


FIG. A.

motors (thus obviating the use of the rotary converter), and they do not sufficiently consider the great dissimilarity between the conditions obtaining in Switzerland and England. As in most other applications of electricity, so is it with traction work: alternating-current systems have a complete region of their own where their advantages are paramount, while there is another region in which the claims of the continuous-current system are equally paramount. It is also certain that no one can draw a definite line of demarcation between the two, but that, on the other hand, there is an ill-defined region where the advantages and disadvantages of both systems overlap, and some engineers advocate the adoption of the one, while others advocate the adoption of the other system.

I suppose no one will question the advisability of the adoption of the series motor for such street railways as are found in Leeds, Liverpool, etc., where the area covered is comparatively small, where generation and distribution of continuous current at 500 volts can be effected with great economy, and in fact where all conditions are in favour of a continuous-current system throughout. This is the region where the claims of continuous-current systems are paramount.

Mr. Field. When we, however, come to mountain railways, we have to acknowledge in most cases the superior claims of the three-phase system. Imagine a generating station miles away from the line, located just where an available mountain waterfall is to be found, the sub-stations far up among the mountains in inaccessible positions, often half buried in snow, and then say what could be more suitable than transformers, requiring no oiling, attendance, starting up, and switching about, but merely doing their duty without attendance, transforming the high-tension three-phase current to low-tension three-phase current, and supplying the same to the trolley wires.

Then, again, since there are few branches and crossings, the overhead construction is comparatively simple, and its unsightliness of small importance. There are very few stops or stations, and speed variation is not needed; indeed, many railway promoters consider an absolutely constant speed a great advantage, since, as long as his motor remains in circuit, the motorman cannot exceed his speed limit on the down gradients, a fact which goes a long way in obviating panic among the passengers on such gradients as 25 per cent. The overhead construction is slightly complicated, but not to any very large extent, because there are not many branches. If it is a little unsightly it does not matter on mountains. There is no doubt that is the region where the claims of the three-phase motor are paramount.

Another instance where the three-phase motor will be perhaps most advantageous is that of very long railway lines with stations far apart, where practically constant speed is possible, where the trolley wires must be supplied at two or three thousand volts, the current being transformed down to a suitable value for the motors by transformers carried on each locomotive.

When, however, we come to systems like those of Dublin, Middlesbrough, and Central London, where the transmission of power, it is true, is effected by three-phase currents at high pressure, we still, in view of the variable speed and frequent stops, require an efficient method of speed control, and an economical system of obtaining great train accelerations, as is afforded by the series-parallel controller in combination with the series motor, rather than by the wasteful method of inserting resistance in the rotor circuits. Again, we cannot afford to complicate the overhead construction; while its unsightliness in cities is a most objectionable feature, the problem of the conduit and surface contact systems becomes far more complex, while the inaccessibility of the sub-stations can no longer be urged as a valid ground against the use of rotating machinery.

I will just take one instance, viz., the Central London, since Mr. Swallow referred to that system at the last meeting. There are on this railway some thirteen stations in a length slightly over six miles, giving an average distance of under half a mile between stations. The average speed is reckoned at fourteen miles per hour, whereas the maximum rises to over thirty miles per hour.

If, then, we draw out the velocity time curve along the route we get a diagram something like Fig. B. If, now, at the maximum speed of, say, thirty-two miles the motor is not to retard the locomo-

tive, we may draw the hypothetical speed as shown, in which case we see that at every instant the horse-power being usefully utilised in propelling the train, is to the horse-power wasted in rotor resistance in the ratio of those portions of the vertical ordinate below and above the speed curve respectively. For example, in the diagram a vertical ordinate has been drawn at time = 220 seconds from start. If at this instant we represent the useful work being done by motors as the length of the line *a b*, then *b c* will similarly represent the lost power in the rotor circuits. Bearing this in mind, compare the case of the Central London with that of a mountain railway, where a constant speed is maintained between stations very far apart, and hence where the acceleration demands an insignificant portion of the total energy required for propulsion of the train between two stations. A glance at the proportions of area above and below the speed curve in the two cases will suffice to show that, however advantageous the Mr. Field.

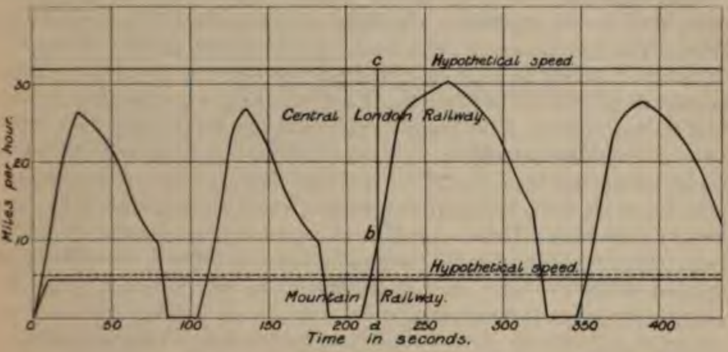


FIG. B.

three-phase system may be for mountain railways, we certainly cannot apply the self-same arguments in the case of the Central London.

Before jumping to the conclusion that the three-phase system is even the best for the Burgdorf-Thun railway, let us consider the alternative that lay before Messrs. Brown, Boveri, who equipped the line.

We must not lose sight of the fact that they had *not* developed the series motor, and the series-parallel controller, with all the accessory continuous-current railway apparatus, for years past; whereas the three-phase motor had been their chief speciality. While with the three-phase motor they were probably in advance of everybody the whole world over, they were in ordinary small continuous-current motors and dynamos certainly behind the standard American practice, let alone the special line of continuous-current railway material. On the one hand they were absolutely sure of success if they adopted the three-phase motor; on the other hand, to have adopted the series motor would have entailed an almost completely new departure on their part: and I can imagine that these alone, and apart from all other reasons, would have been sufficient to warrant the decision in favour of three-

Mr. Field. phase motors. If, on the other hand, they had developed the series motor and accessory apparatus through years of experience, and brought it to the same state of perfection that American practice has, we should not have been very surprised to see Messrs. Brown, Boveri adopting rotary converters on the Burgdorf-Thun line. I consider the case for the three-phase motor far from proved. What we really need are figures of B.T.U. per ton mile, measured at the train and in the generating station, before the matter can be accurately discussed.

[*Communicated.*]—In railways such as the Central London, where the runs are very short, and rapid accelerations essential, too much attention cannot be paid to the shape of the velocity-time curves. Clearly the area of the curve represents space passed through, consequently we see that there are any number of ways in which the same space may be covered in the same time, it being only necessary to make the area of each velocity-time curve the same.

For example, in Fig. C each of the three curves includes the same area, and hence represents the same space passed over in the same time. The initial acceleration and time occupied in accelerating is, however, different in each case, and we see that the greater the initial acceleration and the shorter the time occupied therefor, the smaller will be the velocity of the train when the brakes must be applied. The two extreme cases would be: 1st, where the acceleration was extremely rapid, so that the train would be coasting a great part of the journey, and the final velocity when the brakes were applied would be very small; 2nd, where the acceleration was more or less constant up to the time when the brakes would have to be applied These would then be applied when the train was at its maximum velocity, and since the energy absorbed is proportional to the square of the velocity, this would manifestly be a very inefficient procedure. The tendency is, therefore, to obtain very great accelerations, coast a large proportion of the run, and thus reduce as far as possible the final velocity when the brakes are applied. Of course, the acceleration cannot be increased indefinitely for other reasons, such as passengers' comfort, power of motors, etc., but still the consideration is of utmost importance. As a result, we find that the train is being accelerated more or less uniformly for from $\frac{1}{3}$ to $\frac{1}{2}$ the journey in which time it reaches its maximum velocity, the current is then instantly cut off, and the remainder of the run is occupied with coasting. The train consequently only runs at its maximum velocity for one instant, and never maintains this for any length of time. Now during a great part of the time taken for acceleration, series motors, if employed, would be in one or other of their "running" combinations, that is, with all resistance cut out, and would therefore constitute a fairly efficient arrangement. A three-phase motor, on the other hand, would only be working with anything like a reasonable efficiency for one short instant between two successive stations, viz., when the train was running at its maximum velocity; and until an efficient variable speed motor or reliable variable gear has been introduced which can be handled as readily as an ordinary series-parallel controller, the series motor will undoubtedly outrival the three-phase motor for such railways.

Mr. A. E. Levin: Mr. Hammond at the last meeting suggested that a few data as to the cost of the kilowatt-hour in water-power stations in Switzerland would be of interest. It is a little difficult to give the cost per kilowatt-hour, for the simple reason that very rarely indeed is the charge made for power by meter. In Zürich, and a few other large towns where the load is principally for lighting, and the conditions approximate, more or less, to the lighting circuits of our cities, meters are employed, but in all other cases the charge is made at a fixed rate per annum for every lamp installed or for every b.h.p. of motors. In the case of lamps the charge is usually 20 to 25 francs (16s. to £1) for a 16-candle power lamp. This charge is sometimes modified in the case of lamps in bedrooms which are seldom used. But the charge for motors is perhaps of more interest. A graduated scale is generally adopted for small or large motors. In the case of small motors the price will vary usually between 200 and 250 francs (£8 to £10) per annum for every b.h.p. installed. In the case of larger Mr. Levin.

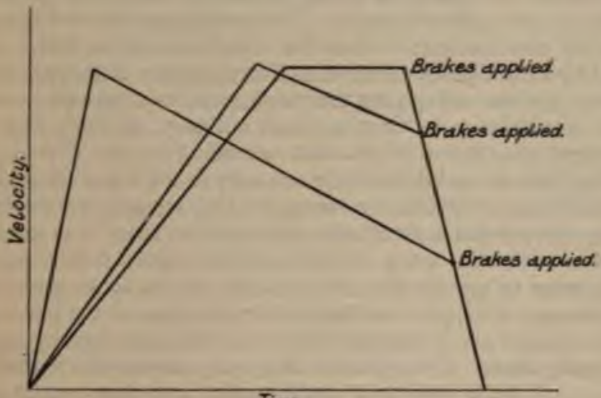


Fig. C.

motors, up to and above 50 h.p., the price may be as low as 150 or 180 francs (say £6 or £7) for every b.h.p. installed. These prices are based on factory use, that is to say, about 3,000 hours in the year, but it is only rarely that any special conditions are made for motors employed either intermittently or day and night. A very fair average may therefore be taken as 150 francs for 3,000 h.p. hours, which would work out at 5 centimes (or about ½d.) per b.h.p. hour. The b.h.p. hour, taking into account the efficiency of the motors, the loss in the line and transformers, will approximately correspond to 1 kilowatt-hour generated in the power-house. It is true that there is one exceptional case where power is sold for carbide production at the low rate of 60 francs per annum per b.h.p. The power is in this case used for 24 hours a day, and 365 days a year, so that the cost would work out to $\frac{1}{14}$d. per kilowatt-hour. But in this particularly happy case the financial and technical conditions were so favourable that it must not be taken as at all typical.

Mr. Levin

Another point which has been very noticeable among the different speakers is the very great impression that was made by the three-phase traction plant in Switzerland. I must endorse what Mr. Field has just said, for I believe that much too favourable an impression has been produced. The Burgdorf-Thun railway especially, and other three-phase traction plants are seen working very satisfactorily, but it is, possibly, a false idea to take away that therefore the system is the best for all, or even for some, cases. By dint of careful workmanship and good mechanical execution in general, these railways are made to work exceedingly well, but I believe the system is open to very serious objections inherent in it and quite apart from any question of mechanical design. In comparing the continuous-current series traction motor with the three-phase motor there are many differences, but the most important lies, perhaps, in the behaviour of the two motors when working under reduced pressure. In the case of a heavy load, when the drop of potential on the trolley line is great, the continuous-current series motor will run at a slower speed, but will have no difficulty whatever in giving its full torque. The three-phase motor is limited in its torque by the tension; in fact the maximum torque which can be exerted by a three-phase motor falls off as the square of the pressure. In designing the line and spacing the transformers of a three-phase traction line it is necessary to bear in mind not only, or even chiefly, the economical distribution of material according to the Thomson law; balancing interest and depreciation on copper and transformers against the cost of the power lost. One must also take into account the fact that the drop of potential must at no time become so heavy that the motors will refuse to do their work. It may, and frequently, I believe, will, arise that in order to prevent the refusal of the motors to do their work a larger amount of copper must be put into the lines, or the transformers must be spaced closer together than would be warranted by questions of economy alone. Even granted that such a calculation is made, it is obvious that there may arise contingencies and emergencies such as the breakdown of one train, requiring two trains to be coupled together, or exceptionally heavy holiday traffic, when the load will be greater than was ever contemplated before, and the drop of potential on the line may be too great and the motors will refuse to do their work. With the series continuous-current system, whatever the load may be, whatever contingencies may arise, if there is any pressure at all on the line the motors will crawl along and will give their torque even if they go much more slowly.

It has often been urged that a great advantage of the three-phase system lies in the fact that a higher pressure can be adopted. Is it quite certain, however, that the limit of pressure, with continuous-current working, has been reached? Is there any reason why continuous-current series motors for traction work, at all events of 60 to 100 h.p., should not be built for 750 volts quite as well as the three-phase motors now running on the Burgdorf-Thun line? It is true that the Board of Trade at present limits the pressure for continuous currents to 500 volts, but it also limits the pressure of alternating currents to 300, so that in either case we are above the limit. The

objection that standard city lines are made for 500 volts is scarcely of great importance, for there seems to me no reason why inter-urban lines should not be made for running at a pressure of 750 volts, while the same cars entering the city limits would run on to the 500 volts at a reduced speed. If three-phase traction will allow us to go to much higher pressure—to several thousand volts—then indeed a great advantage is laid before us. A line has been under construction for some years from Lecco to Sondrio in North Italy, where a pressure of 3,000 volts is to be employed on the trolley line. Messrs. Ganz & Co., of Buda-Pesth, are constructing this line, but I have not heard of any actual runs being made on it. This pressure will be employed in one motor, while another motor, carried on the car, will take its pressure from the rotor of the first, which will therefore, in certain cases, be employed as the transformer. If any favourable results are obtained from this line, a very strong case will be made out for three-phase traction; but until we hear more of that, I submit that the general applicability of three-phase traction must be regarded at least as not proven. Mr. Levin.

Mr. A. P. TROTTER: I was surprised during last week's discussion to hear gentlemen talking of three-phase traction on the Central London Railway. Many of the objections to such practice have already been given by previous speakers. Those who have studied the practical working of the London railways, the City and South London, and the City and Waterloo lines, must see the importance of the variation of speed, and the diagram (Fig. B) given by Mr. Field undoubtedly shows us fairly well what will happen on the Central London Railway. Advocates of the three-phase system have not attempted to explain how it can possibly be used economically upon such a line as that. The three-phase system on the Burgdorf-Thun line was a splendid and most interesting piece of work, but economy was not of much importance there, as we know. I hope that those who are recommending us to adopt the three-phase motors for such purposes will suggest how it is possible to compete in economy of working with continuous current. Mr. Trotter.

Mr. Ferranti has spoken about the complication of the switching arrangements in ordinary three-phase station work, but surely the diagrams which we have seen to-night of the gearing of the Jungfrau locomotive show the serious handicap against which those who are using alternating current have to struggle. Of course there are great advantages, as we have heard to-night, for rack railways, where there is "collar-work" all the way up and a good, safe brake coming down; but it does seem that there is room for a considerable amount of simplification in the locomotives and switching gear.

Mr. G. L. ADDENBROOKE: I should like to refer to two points which were brought forward at the last meeting, one by Mr. Swinburne, especially as they bear on some remarks of Mr. Ferranti's to-night. Mr. Swinburne spoke of the development of electricity in Germany and Switzerland, and the way that it had advanced in comparison with this country, and he said that it would be desirable to know something more about the way in which the finance has been Mr. Addenbrooke.

Mr. Addenbrooke.

worked there. It is a curious fact that, although a very large proportion of the lighting in Germany is done with capital provided by the towns themselves, it has been done in such a way that it has actually strengthened very much the electrical profession and industry, whereas in this country it has been done in such a way that the reverse is the case. The work in Germany has been very largely done by a town first arranging to carry out the lighting, and then, usually, letting their contract to one large firm with an arrangement for running the whole for a series of years. That firm has then obtained financial aid from a bank, and they have had the whole thing in their hands. That method of doing it has certainly resulted in some very successful installations, and it has also led to the great German manufacturing companies becoming very powerful, and succeeding better financially than their British competitors. The consequence has been that they have very large sums of money at their disposal, they are in touch with the finance of the country, and it is very much easier to get electrical projects of all sorts carried through there than it is here, quite apart from the question of the attitude of the Legislature, which has, without doubt, in this country, been most unfortunate. There may be something done to remedy that later on, but it has had a most detrimental influence.

Then there was a point brought forward by Mr. Hammond. When you go to Switzerland and see the electrical power distribution there, the obvious inference is, if you have not got water-power here cannot we do the same thing by steam? This, however, is not a fair inference to draw, as the conditions are not absolutely the same. In Switzerland they have very expensive coal, and water-power at a very low price, or practically for nothing. There, if they are to have power at all it is very advantageous for them to utilise their water-power. On the other hand, in England we have cheap coal and we have steam-engines. Therefore the problem is, can we replace steam-engines by power generated in a central station? Those two problems are different problems, and if you do not want to have a financial wreck it is very important to distinguish between them. It is not, as Mr. Hammond put it on the last occasion, a mere question of the cost of coal, for this comes in but to a very small degree. When I was working out the figures for the Midland Electrical Corporation I went to a friend in the City who was the engineer of one of the steamship companies, and I asked him what were the figures now which were being used in the design and running of marine engines. I said I did not want mere test figures, but the sort of figures they expected to get on ordinary runs. He told me that his company were then building five steamers in one contract, and they were built on a basis that they should use 1·4 lb. of Welsh or Newcastle coal per I.H.P. hour in actual running. That is the sort of figure you cannot very well get behind. Of course, if power-stations are established in this country they will employ poorer coal than that and use rather more of it; but still, if we take it that about 1,000 h.p. hours can be got out of one ton of coal, and that you can get one ton of coal (except at the present tim when coal is very dear) for something like five

shillings, of course the cost of coal does not seriously affect the question, but the question of electrical distribution versus steam locally generated is very largely one of capital cost. Mr. Addenbrooke.

In the discussion on Mr. Holliday's paper I put in (see page 85) a table of the actual cost of steam plant, in which I showed that the cost of a 50 h.p. steam-engine, complete in every detail, came to something like £20 per I.H.P. If you put up a large central station with distributing mains and motors to do the work of that steam-engine you will have to put in an expenditure of £50 or £60 per B.H.P. of the motor. The problem is, are the savings you can get in generating steam in a central station, and under better conditions, such as to justify the difference in capital expenditure between, say, £20 per I.H.P. for a 50 h.p., or £14 per I.H.P. for a 100 h.p. engine, since the cost comes down as the power increases? Are the conditions such as to justify that extra capital expenditure and pay interest on it? That is a matter which requires very careful consideration in any power scheme.

Mr. L. GASTER: If I rise to say a few words, it is only as an old pupil of the Zürich Polytechnikum. The Report of the Committee shows the enormous progress which has been made, and I should like to say that the laboratories in the Polytechnikum, which are at the disposal of the students, have helped very greatly to develop electrical engineering and the industry in Switzerland. If you consider the great advantage the Polytechnikum derives from being the only institution of its kind in Switzerland and from having a grant from the Government sufficiently large to cover more than three-quarters of the total expenses, you will readily understand how easy it is for students to have cheap education, and so to remain for the three or four years which are necessary to complete their training. Hence you find that the Swiss engineers are high-class and educated men, who have been taught just as well as at the Universities, and have, in many cases, been able to obtain the Doctor's degree if they so chose. I may say that the labours of Professors Weber, Wyssling, and Stodola, of whose assistance the institution has the advantage, as well as the other professors, have helped very greatly to raise the status of Engineering Education there. Mr. Gaster.

I cannot allow this occasion to pass without speaking on behalf of my Swiss colleagues of the Polytechnikum, after hearing the way in which you have thanked us for the hospitality which you enjoyed when you came to Switzerland. I may say that I am fortunate enough to live amongst you in England and to enjoy your hospitality, and I am sure that when the Swiss come over to England, they will find the English as they are, and not as they are painted by certain Continental journals. They will find also quite enough work here to appreciate, and when they go home they will be proud to have met such colleagues.

Mr. W. M. MORDEY: As a member of the Swiss Committee I am receiving an honour that I am not entitled to—practically the whole of the work was done by your President, assisted by his very able lieutenant, Mr. McMillan. Mr. Mordey.

Mr. Mordey.

We shall keep for study many details of practice observed, and we shall watch with very great interest the development of the new things we saw during our visit. One of the lessons we may safely learn from that visit is, as I said speaking on one of the occasions when we met our Swiss hosts, that the present indications incline us to look to Switzerland rather than to America for guidance for future practice. Although the Americans have done great service in the development of electrical engineering, I fear they are settling down to a fixed idea—that they have one duty in life, viz., to sell what happens to be American standard plant at the time, and to persuade the world that it is standard plant for all time. This is having a prejudicial influence not only in America, but here. We are preparing to meet the demand in this country by following American examples rather than by developing what the Americans would themselves no doubt like to produce if they could start with a free hand. Let us watch these experiments in Switzerland, and wait a little and see what happens. My own feeling is that a great deal of the complicated machinery that is now being put in for transforming purposes will be swept away. As the President said in his Address, referring to direct-current machinery, we really use alternate currents in the motors and we generate them in the generators, and we twice commute them in the intermediate stages. Surely we can get rid of these intermediate steps and make direct use of alternate currents.

One thing I was struck by in Switzerland; and I have been struck by the same thing in Germany, Austria, or Hungary. The men who are actually controlling the works and the businesses are practical men, not under the control of boards of directors who have usually no technical knowledge and very often very little business knowledge. It has been asked why in Germany and Switzerland the bankers support the manufacturers. I suggest one reason is that the financial people have confidence in engineering work controlled by such practical men—more confidence than if the work were under the control of men whose objects are very often entirely different. I am very glad Mr. Trotter is here to-night, for in Switzerland we saw how very well they got on with the minimum of control by the authorities. Another thing struck me was that the scientific institutions there realised that they are primarily formed for the purpose of helping industry. They do not say: "You must not come anywhere near us with your electrical tramways because you will disturb our measuring instruments." It is not very long ago that we heard in London of strong opposition to an underground electric railway because it was going to interfere with the experiments in a certain excellent institution; as if the importance of such work—and I do not deny its importance and usefulness—could for one moment be compared with the necessity for lessening the congestion of the traffic of London. I never heard anything at Zürich about people wanting double wires so that there should be no earth currents to disturb the work at the famous Polytechnikum—they are there to help industry, and not to hinder it.

Professor Perry.

Professor PERRY: They could shield the instruments with iron.

Mr. Mordey

Mr. MORDEY: Exactly. The first use scientific people ought to

make of their knowledge is to make instruments which can measure things in this world where electric currents and magnetic fields are being produced in every centre of population.

Mr. Mord[illegible]

Professor Perry.

Professor PERRY: There is one thing you cannot shield, viz., terrestrial magnetism. If you did that you would be shielding the thing you wanted to measure.

Mr. Mord[illegible]

Mr. MORDEY: I do not want to get on to that subject, but if we must measure terrestrial magnetism in this country—and I have no doubt it is a useful thing to do—let us measure it where it is terrestrial magnetism, but not in the midst of a vast industrial population where it is mixed with all sorts of magnetism besides terrestrial. It may interfere with the continuity and the uniformity of records and experiments to move the apparatus away from Greenwich or Kew to the highlands of Perthshire or somewhere like that, but I suspect the real objection is that it would move the observers away too. In another way the manufacturers in Switzerland seem to work under no restriction, they have not consulting engineers—at least if they have they are tame ones. They specify, if they specify at all, what they can get easily and cheaply. They do not specify all sorts of conditions. Therefore it is that Swiss manufacturers make things with very much greater freedom as to design than is possible in this country. I should like to say one word about the Central London Railway. Something has been said casting a reflection upon the engineers of that line. If any of us had been in the proud position of those engineers, I think we should have done most of the things they have done. They had to put something down which they knew would work—they could not make experiments. People talk as if the engineers, ought to have put down an alternating system. But you must remember that the Burgdorf-Thun line was only started a few months ago, whereas the Central London was thought out years ago. They put down alternate-current generators, and if they find later on that they can sweep away all that complication of transformers and take their alternating current direct to their motors, at any rate they have an alternating current there to start with.

In conclusion, I wish to reiterate on behalf of the Committee, and I am sure on behalf of the whole Institution, our very grateful thanks to our Swiss hosts and fellow engineers for the very splendid way they received us, and for the very good time they gave us generally. I would add one reason why we should repeat these foreign visits, the reason something like one given by Cowper—

> "How much a fool who's been to Rome.
> Excels a fool who stops at home."

How much more therefore, etc.! Q. E. D.

AN ELECTROLYTIC CENTRIFUGAL PROCESS FOR THE PRODUCTION OF COPPER TUBES.

By SHERARD COWPER-COLES, Member.

INTRODUCTION.

The electro-deposition of copper is now carried on in many large engineering works for the coating of hydraulic rams, barrels of guns, shell and shot, and is extensively employed in the manufacture of tubes and sheets, and for the production of large copper vessels; most of the copper used by electrical engineers is refined electrolytically. Over one-third of the total copper output of the world is now electrolytically refined. It is difficult to obtain exact figures, as the copper returns for various countries do not distinguish between raw and electrolytic copper; but it is estimated that one-half of the copper produced in the United States in 1897 was electrolytically refined, and in 1898 the proportion was slightly over that amount. The demand for electrolytic copper is on the increase, and the capacity of most of the electrolytic refining works has been or is being increased.

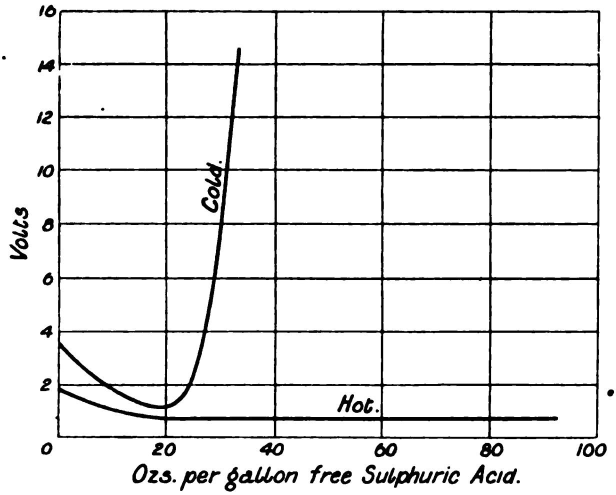
PROGRESS AND EXTENT OF THE ELECTROLYTIC COPPER REFINING INDUSTRY.

The following figures published in *Industries and Iron* show the rapid growth of electrolytic refineries. The world's total output of electrolytic copper 15 to 20 years ago, did not exceed 10 to 15 tons a week. In 1881 to 1882 this amount was probably increased to about 60 tons as the result of the refineries erected in Swansea. During the next four or five years several of the American refineries got to work, and by this time, say 1888 to 1890, the world's total production was probably not more than 280 to 300 tons per week. Since that date, up to the present time, many refineries of gigantic size have come into existence, not only in America, but in England, France, Germany, and even Japan, and it is quite safe to estimate the world's production at the present moment at no less than 500 tons per day, or about 180,000 tons of electrolytic copper per annum, and

during the refining of this quantity of metal there are not less than 20,000,000 ounces of silver and 100,000 ounces of gold recovered. When these weights are converted into money value, the following astonishing figures are obtained:—

Annual Copper value	...	... ...	£9,000,000
„ Silver „	...	... ...	£2,500,000
„ Gold „	...	... ...	£400,000

or in round numbers, a total value of £12,000,000 sterling.



CURVE I.—Curves showing the Effect of Free Sulphuric Acid on the Voltage in Hot and Cold Solutions of Copper Sulphate.

This startling result has been achieved in a maximum of twenty-five to thirty years : this industry has had a growth probably unparalleled in the history of commercial enterprise.

INCREASE OF CURRENT DENSITY IN COPPER REFINERIES.

It has been the object of those engaged in the electrolytic refining of copper to increase the current density as much as possible, so as to get a larger output per vat. A considerable increase of current has been effected of late years by attention to details, such as—

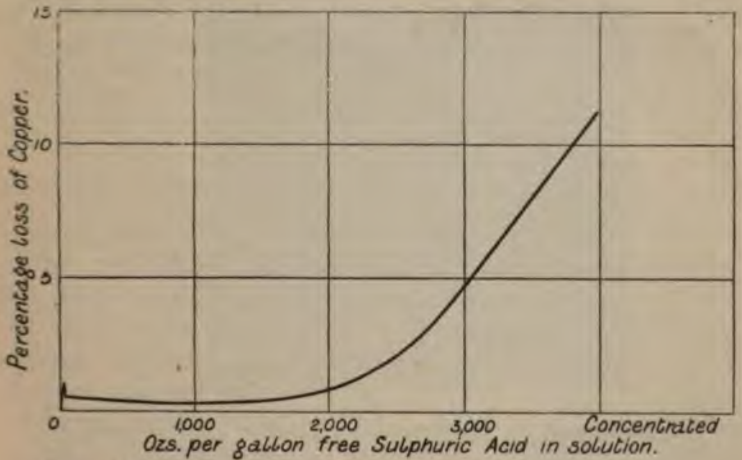
1. Proper circulation of the electrolyte.
2. The purity of the electrolyte.
3. The chemical composition of the electrolyte.
4. The arrangement of the electrodes.

In a review of the position of the electro-copper refining industry by Mr. Titus Ulke, he mentions that it was not at all uncommon ten years ago for the copper refiners to stock their tanks with 75 to 100 times as much copper as was daily produced in everyday work. This enormous disparity has been gradually reduced, so that to-day only one-fourth to one-fifth of that amount is required, or an average of fifteen to twenty tons per ton of output. He attributes the cause of this marked improvement to the method of handling the baths, and especially to the higher current densities now made practicable. Whereas formerly, currents of only two to four amperes per square foot were thought permissible, to-day current densities of from fifteen to twenty amperes are said to be employed in some establishments, and the end is not yet in sight. The conclusion arrived at by Mr. Ulke is that the average proportion between the total copper in process of treatment, and the yearly capacity (measured by output) in our electrolytic copper works, is now about 4 per cent. as against two or three times that amount formerly, and that the average proportion is likely to diminish still more within the next year or two.

Description of Various Methods for Improving the Physical Properties of Electro-deposited Copper.

One of the best-known electrolytic processes for the manufacture of tubes is that in which an agate burnisher is used for consolidating the deposit during electro-deposition. This process has met with considerable success, the chief drawback being the tendency of the copper to laminate or exfoliate where the burnisher has been at work, the pressure on the burnisher requiring to be regulated to a great nicety. Elmore has sought to build up electro-deposited tubes equal to drawn ones by causing a burnisher to constantly traverse the length of the tubes backwards and forwards, as they slowly rotate in the bath, and so obtain a copper possessing a high density. The current density originally employed for this

process was about sixteen amperes per square foot, but this the author believes has been considerably increased. Copper deposited by the Elmore process has stood a stress of 26·5 tons per square inch, with an extension of 16·5 per cent., the limit of elasticity being reached with a load of 23·3 tons per square inch, the specific gravity of the metal being as high as 9·2. Von Hübl has succeeded in producing, by simple deposition without the aid of a burnisher, a specimen of copper which broke at a stress of 23·6 tons; commercial cast copper breaks at about 8·4 tons per square inch. Another process, that is now being operated on a large



Percentage = 86·2 92·59 94·93 ——

CURVE 2.—Curve showing the Solubility of Copper in Sulphuric Acid.

commercial scale, substitutes a sheepskin burnisher for an agate one, smooth deposits being obtained by the application of an insulating coating to the inequalities on the surface. The sheepskin impregnators, which move over the surface of the metal, coat all projecting parts with a thin film of animal fat, which hinders further deposition until the surrounding depressions have been raised to the common level. In later patents impregnators are mentioned composed of organic gelatinous or albuminous matter free from excess of grease, rendered insoluble by treatment with bichromate, or the softening of the albuminous or gelatinous constituents of the impregnators is prevented by soaking

them with a solution of formic-aldehyde (within the limits of 10 per cent. and 40 per cent.), after which it is washed in water to remove the aldehyde, or this substance is neutralised or decomposed by means of sulphuric acid. It is claimed for impregnators so treated that they may be employed with equal facility in a hot or cold bath. The current used is from 35 to 40 amperes per square foot of cathode area, the voltage required is about 1·6 per vat. Tubes are deposited 12 feet in length and 16-inch diameter, and ¼ thick; these are longitudinally cut and opened to form sheets. Several investigators have patented methods to improve the physical properties of electro-deposited copper by injecting the electrolyte on to the copper during deposition. Craydon Poore has devised a method for producing plates by projecting the electrolyte forcibly on to a cathode placed in a horizontal position.

Centrifugal Copper Process.

The author has lately developed a centrifugal process, which is now being worked on a practical scale, for copper refining and the manufacture of copper tubes, sheet and wire by electro-deposition, which does away with the troubles of lamination and enables a much higher current density to be used than has hitherto been the case, smooth tubes having been produced 12 inches in diameter at the remarkably high current density of 200 amperes per square foot, the voltage being from ·5 to ·7. Solid drawn copper tubes of such diameters cost about three times the price of tough copper cake. The centrifugal process is distinct from those already referred to, inasmuch as there are no burnishing tools employed, but the cathode on which the copper is deposited is revolved at a high rate of speed, the result being that the skin friction, between the deposited metal and the electrolyte, keeps the copper beautifully smooth and compact. Any gas bubbles evolved at the cathode, or impurities in mechanical suspension in the electrolyte which would have a tendency to settle on the cathode, are thrown off by centrifugal force. Mr. J. W. Swan has found that regularity and smoothness of deposit were almost entirely dependent on the absence of solid particles held in suspension in the electrolyte, and that excrescences could be en-

1.

2.

3.

4.

5.

FIGS. 1 TO 5.

tirely avoided by taking care that the electrolyte was free from solid floating particles. He observed that at the seat of each "nodule" was a speck of some foreign substance. Dr. G. Gore has given the matter some thought, and has observed that the greatest length of "nodule" is in the direction of the greatest intensity of current and amount of copper in solution. The centrifugal action is clearly illustrated by the following photographs. Fig. 1 shows the cathode mandrel stationary. Fig. 2 shows the mandrel directly after it has started to revolve; the gas is distinctly seen being thrown off by centrifugal force. Fig. 3 shows the mandrel after it has been revolving for five minutes. The photographs also show the heavier solution or anolyte descending from the anode. On the table are a number of specimens of tubes and sheets produced by this process, some at a current density of 200 amperes per square foot, which were deposited from solutions of approximately the following composition; the copper anodes containing about 30 ounces of silver to the ton:—

	Ozs. per gal.	Percentage.
Copper Sulphate ($CuSO_4 5H_2O$)	22·44	10·95
Sulphuric Acid (H_2SO_4)	22·34	10·90
Ferrous Sulphate ($FeSO_4$)	·05	·02
Water	160·00	78·13
		100·00

The following series of photomicrographs show the results obtained with rapidly revolving and stationary cathodes, all other conditions being the same:—

			Electrolyte
Fig. 6.	100 amperes per sq. foot,	revolving	Hot
Fig. 7.	150 „ „	„	„
Fig. 8.	220 „ „	„	„
Fig. 9.	40 „ „	„	Cold
Fig. 10.	40 „ „	stationary	Hot
Fig. 11.	100 „ „	„	„
Fig. 12.	10 „ „	too much grease on mandrel	Cold
Fig. 13.	10 „ „	no grease on mandrel ...	„
Fig. 14.	Copper crystals from a voltaic cell.		

The apparatus employed for the centrifugal process consists of a wooden vat "A" Figs. 15 and 16, in which are placed anodes composed of crude copper. The cathode is

a hollow mandrel "B" made of brass, which is supported on a revolving shaft "C." The shaft is brought through the bottom of the vat to the top of the cell, and is protected from the acid copper sulphate solution by a lead-cased wrought-iron column. The shaft is caused to revolve by gearing placed beneath the depositing cell, the speed varying with the size of the mandrel employed. The mandrel at one end is fitted with an eye bolt "D" for lifting purposes, and a circular brass casting "E," against which the contact brushes "F" rub for collecting the negative current. The brushes are fitted to arms "G," which are made to turn back to allow of the easy withdrawal and insertion of the mandrel. "H" is a baffle plate made of an insulating material, placed at the bottom of the mandrel to prevent the formation of copper "trees" or "nodules"; figures 17 and 18 show the "trees" and "nodules" which have a tendency to form if a baffle plate is not used. The electrolyte is briskly circulated through the cells by means of an acid proof pump, the solution being forced or pumped to a reservoir, where it passes through a filter to rid it of all impurities in suspension. When it is desired to obtain a sheet of copper, the tube, after being removed from the mandrel, is cut, flattened out, and annealed; when a wire, a piece of insulating material is wound round the mandrel in the form of a spiral, and copper deposited between the threads until the thickness of copper is equal to the distance between the threads, the spiral is then removed, and after annealing is drawn out in the usual manner. The mandrel is given a small taper, and is slightly greased to facilitate the removal of the tubes. Figs. 19 and 20 show a modified arrangement for driving the mandrel above, instead of from below. Another interesting feature of the centrifugal process is that it enables a hot and more acid solution to be used than is generally employed. Figs. 4 and 5 are photographs of two copper deposits. All the conditions are similar with the exception that the mandrels were revolved at different speeds. No. 4 was revolved at about 30 revolutions per minute; No. 5 at 1,000. In the first case copper came down as a loose mud, so the photograph shows the deposit on the mandrel. In the second case the copper came down smooth and bright, and was expanded off the mandrel as a perfect tube. The current density was 170 amperes per square

foot and the temperature 160° Fahr. The electrolyte was of the following composition :—

	Ozs. per gal.	Percentage.
Copper Sulphate	30	12
Sulphuric Acid	60	24
Water	—	64

The amount of free acid has a very marked effect upon the voltage required, but a very small effect upon the actual weight of copper obtained, compared with the theoretical weight, as shown by the following table and Curve 1; the amount of copper sulphate was 32 ounces per gallon of water = 16·66 per cent.

TABLE I.

No.	Current Density.	Solution, Cold.		Percentage of Free Acid by weight.	Peripheral speed. Feet per minute.
		Voltage.	Ozs. of H_2SO_4 per gallon by weight.		
1	100	3·5	0	·0	471
2	100	2·5	6	3·03	471
3	100	2·0	8	4·00	523
4	100	1·8	10	4·95	471
5	100	2·2	25	11·52	523
6	100	8·0	30	13·51	523
7	100	12·0	40	17·24	471
8	100	14·0	60	23·81	523
9	100	20·0	100	34·24	628

The solution was circulated at such a rate that it was renewed in the depositing cell every five minutes. The above table shows the advantage of increasing the acidity of the solution up to a certain point, and the disadvantage of increasing it beyond that point; the critical point seems to be about 15 ounces of free sulphuric acid per gallon, = 7·24 per cent. The rise of voltage in a cold

[redacted]

solution is explained by the fact that the addition of sulphuric acid to a copper sulphate solution causes the copper sulphate to crystallise out; this takes place on the electrodes, and largely increases the resistance. It has been shown that a saturated copper sulphate solution is the best conductor; and that a 25 per cent. solution of sulphuric acid offers the best resistance. With too much acid polarisation ensues from its own decomposition by the action of the current. The latter trouble is said to set in when the copper sulphate solution has reached an acidity of about 13 per cent.; these remarks apply to stationary anodes.

Table 2 and Curve 1 give the voltage required when depositing at 100 amperes per square foot from a solution containing 32 ounces copper sulphate per gallon, = 16·66 per cent., the temperature being 160° Fahr., various amounts of free acid being used, with anodes of commercial copper.

TABLE II.

No.	Current. Density	Voltage.	Ozs. of H_2SO_4 per gallon by weight.	Percentage of Free Acid by weight.	Peripheral speed. Feet per minute.
1	100	3·5	0	0	500
2	100	1·3	10	4·95	500
3	100	0·9	20	9·43	500
4	100	0·8	30	13·51	500
5	100	0·75	40	17·24	500
6	100	0·75	50	20·66	500
7	100	0·7	60	23·81	500
8	100	0·7	100	34·24	500

The solution in this experiment was not circulated. Comparing this table with No. I. the advantage of using a hot solution is shown, also the advantage of increasing the acidity.

Table III. gives the variation of current and voltage due to increasing the temperature of the electrolyte.

TABLE III.

Amperes.	Volts.	Temperature of Solution
0·55	8·0	60° Fahr.
4·00	7·0	70° „
8·00	5·0	75° „
10·00	4·0	78° „
14·00	2·0	82° „
16·00	1·0	90° „
16·00	0·85	100° „
16·00	0·80	120° „
16·00	0·75	140° „
16·00	0·70	180° „
16·00	0·70	200° „

This table shows how a hot solution allows a heavier current to pass at a much lower voltage; 150° Fahr. is probably the most economical temperature to work at. The curve on the diagram was arrived at by dividing the E.M.F. by the current, giving the resistance in ohms.

It is well known that from a neutral or slightly basic solution copper comes down in a coarse-grained brittle condition, whereas the amount of free acid has a very marked effect on the voltage, as is shown by Table II. This may be due to the production of a small amount of cuprous acid from a neutral or basic solution, or to the influence of a large percentage of free acid on the mode of crystallisation of the metal.

Von Hübl has observed that the dark coloured spongy deposits produced by too high a current density occur the more readily the poorer the electrolyte round the cathode is in copper. According to the same authority this dark deposit is not due to the presence of cuprous oxide, but to the formation of a hydride. Hydrogen may under certain circumstances be occluded by electrolytic copper, which

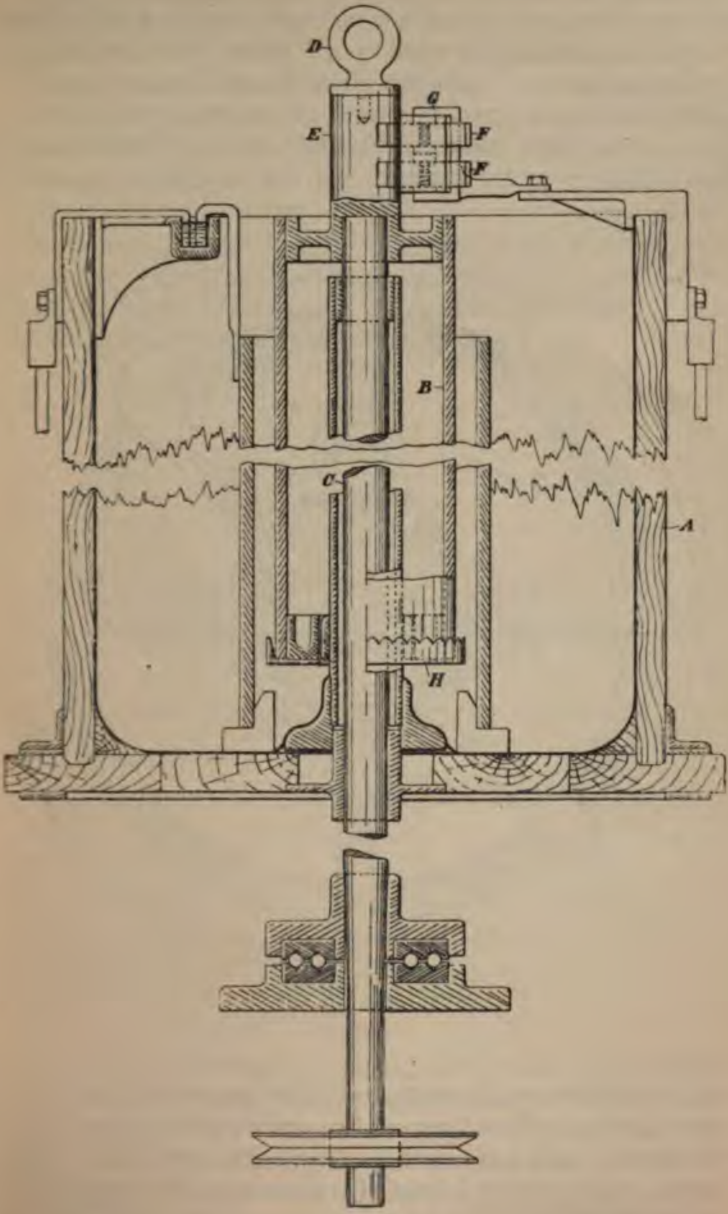


FIG. 15.

has been proved by the analyses which have been made of the gas pumped out of various specimens of the metal. Thus, a certain sample gave up 4·4 times its volume of gas, consisting of 77·3 per cent. of hydrogen, 8·4 per cent. of carbon monoxide, 11·1 per cent. of carbon dioxide, and 3·2 per cent. of water vapour. Foerster & Liedel have studied the influence of temperature on the character of copper

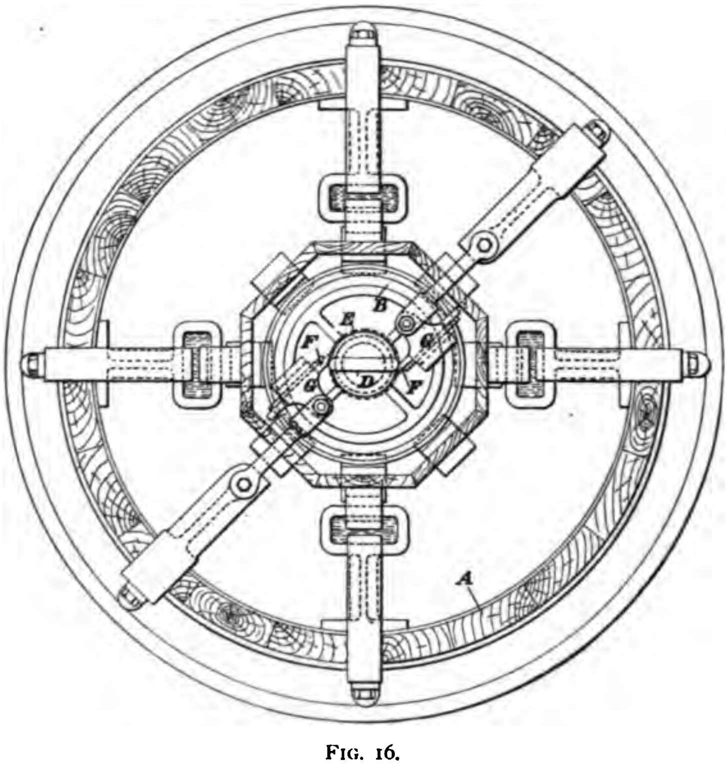


FIG. 16.

deposited from acid solutions. The experiments were not very conclusive, but they tend to show that tougher copper is obtained with hot solutions than with cold. The experiments of Foerster & Liedel also show that the precipitation of brownish red powdery copper is connected with a certain low concentration of the copper ions in solution. Owing to the rapid revolving of the cathode in the centrifugal

process, the solution is kept well mixed, so the difficulty of having the solution poor in metal round the cathode is overcome.

The experiments on the loss of copper by corrosion with a revolving mandrel are not very reliable, but there is no apparent reason why the loss should differ from that with a stationary mandrel. If the solution is kept thoroughly saturated with copper sulphate, the corrosion ought not to be more than a very small percentage of the total copper deposited. This loss might be reduced by using a higher current density; for instance, if the current is doubled the percentage loss will be halved.

On the Loss of Copper by Corrosion.

TABLE IV.

No.	Current Density.	Ozs. of Free H_2SO_4 by weight.	Per cent. of H_2SO_4 by weight.	Loss on Cathode per cent.	Loss on Anode per cent.
1	25	10	4·95	3·0	7·5
2	25	20	9·43	2·7	8·1
3	25	30	13·51	2·8	7·1
4	25	40	17·24	2·2	6·7
5	25	60	23·81	1·8	5·1
6	25	100	34·24	2·5	6·7

In these experiments (run in series) the time, temperature (160° Fahr.) and current were kept the same. The greater loss at the anode is accounted for by the fact that the anodes were all much larger than the cathodes, and therefore a greater surface was exposed to the action of the hot acid.

Table V. and Curve 2 show the solubility of copper foil in sulphuric acid:—

TABLE V.

No.	Percentage of H_2SO_4 per gallon by weight.	Loss per cent. Hot solution.
1	0	0
2	3·03	0·9
3	5·88	0·5
4	34·44	0·49
5	75·75	0·4
6	86·20	0·27
7	92·59	0·7
8	Concentrated Acid	10·7

From this table the solubility of the copper in dilute sulphuric acid appears to be greatest at 3 per cent., and gradually falls until about 90 per cent., a greater increase taking place when concentrated acid is used.

The following table shows a steady decrease in the solubility of copper in sulphuric acid from 10 per cent. to 50 per cent., the copper foil being immersed in the hot for three hours and in the cold solution for fifteen hours.

TABLE VI.

No.	Ozs. of H_2SO_4 per gallon by weight.	Per cent. of H_2SO_4 by weight.	Loss per cent. hot solution, three hours.	Loss per cent. cold solution, fifteen hours.
1	10	5·88	1·27	0·218
2	20	11·11	1·17	0·180
3	30	15·79	1·14	0·145
4	40	20·00	0·85	0·145
5	60	27·27	0·74	0·11
6	100	38·46	0·69	0·97

FIG. 17.

FIG. 18.

[redacted]

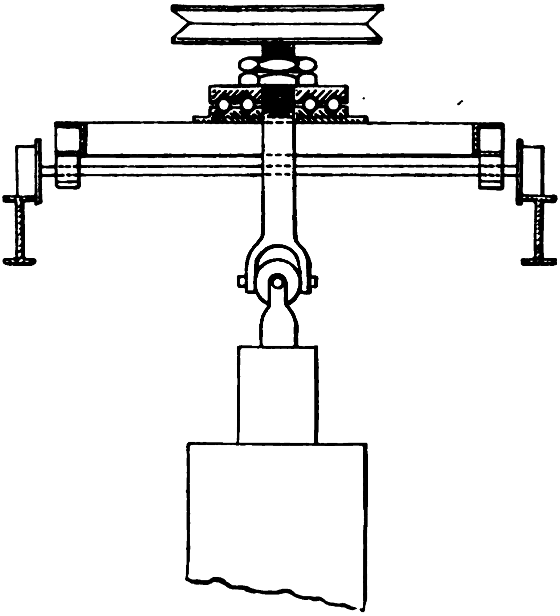


FIG. 19.

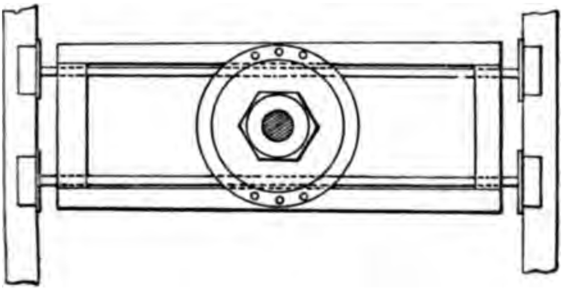


FIG. 20.

Anode Sludge.

As already mentioned, a very high current density can be used with the centrifugal process, and smooth deposits can be obtained with a current density of even 200 amperes per square foot. This is a matter of great importance, as in copper refining with high current densities less anode sludge is formed. It has been observed by Foerster & Liedel that when a high current density and a high temperature are used there is far less sludge formed on the anodes. With a current density of 0·3 ampere per square decimetre at the ordinary temperature, a weight of 0·5 kg. of anode copper consumed left 3·7 grms. of sludge, containing 60 to 70 per cent. of copper, partly as cuprous oxide. Under the same conditions, but working at 40° C. the sludge was only 1·2 grms., and was nearly free from copper. With a higher current density, viz., 1 ampere per square decimetre, the quantity of anode sludge was about the same, at 20° C., and 40° C., viz., 2·5 grms. from 1 kg. of copper. These results, although far from exhaustive, go to show that the high current densities used in modern copper refining have the incidental advantage of reducing the quantity of anode sludge, and thus making the working up for silver and gold easier and more economical. A yet higher temperature, viz. 60° C., increases the quantity of sludge; a good deal of the increase is due to the presence of metallic copper, which may be regarded as having been formed during the spontaneous resolution of cuprous sulphate, momentarily produced at the anode, thus :—

$$Cu_2SO_4CuSO_4Cu$$

Gold is not dissolved from the anode, and silver only to a small extent, and selenium and tellurium not to any appreciable extent when present in small quantities.

Arsenic is found to be most readily soluble, and bismuth least soluble, amongst the impurities in the anodes. According to Dr. Borchers, the mud or slime deposited on the anode may contain, after drying, gold, platinum, silver, silver sulphide, cuprous oxide and sulphide, basic sulphates of bismuth, tin and antimony, antimonic acid, arseniate of copper, and other arseniates and antimoniates, lead sulphate

and slag constituents in which may be iron, lime, magnesia, and silica, and with these there will also be a certain amount of metallic copper in a pulverulent state. If the anode contains too high a percentage of impurity, it leads to several practical difficulties such as the periodical scrubbing of the anodes. Some of the impurities found in electrolytic copper are electrolytically deposited from the electrolyte, and others are mechanically thrown down. Centrifugal action seems to prevent any matter in suspension settling on the rapidly revolving cathode. E. Koller has communicated some interesting figures to the Journal of the Chemical Society. He found that the average composition of the vat deposit obtained (i.) during a year's treatment of reverbatory, and (ii.) from three months' treatment of converted copper, are as follows, exclusive of oxygen and combined water :—

	(I.) Per cent.		(II.) Per cent.	
Ag.	53·894	[0·3064]	55·15	[0·3076]
Au.	0·296		0·198	
Cu.	11·01	[0·0093]	13·82	
Pb.	0·91	[0·0093]	2·07	
Bi.	3·93	[0·0320]	0·34	[0·0035]
Sb.	6·25	[0·0651]	2·44	[0·0510]
As.	2·11	[0·0586]	1·09	[0·0180]
Se.	0·39	[0·0098]	0·72	
Te.	1·17		0·89	
Fe.	—		0·80	
SO_4	5·27		10·68	
H_2O	2·36		2·60	

The numbers in square brackets represent the percentages of the various elements in the unrefined copper, and show therefore the nature and the extent of the refining effected by electrolysis. From these numbers it will be found that the whole of the silver, gold, selenium, and tellurium remain in the residue ; whilst, of the other elements, there are left in the slime, in the two cases respectively :—

Cu., 0·07, 0·08 ; Bi., 78·22, 60·71 ; Sb., 61·14, 29·90 ; and As. 22·90, 37·84 per cent.

Physical Properties of Electro-deposited Copper.

Copper prepared by electrolysis may have as low a density as 8·00; the figure for normal copper is 8·9. Hard rolling, cold hammering, and hard drawing increase the tensile strength, and limit the elasticity of copper considerably. The extensibility of annealed copper becomes less at high temperatures, and that of mechanically worked copper becomes higher. Some copper sheet (not annealed) deposited by the centrifugal process, ·0245 of an inch in thickness, broke at 433 lbs., which is equal to 22·1 tons per square inch. Hard-drawn wire made by this process has a tensile strength of 29 tons per square inch, annealed 20 tons, the electrical conductivity being 99 per cent. The author has obtained excellent tough deposits of copper with the theoretical yield from a solution composed of :—

	Ozs. per gallon.	Percentage by weight.
Copper Sulphate ($CuSO_4+5H_2O$)	32 ...	14·87
Sulphuric Acid (H_2SO_4)	12·6 ...	10·77
Water	...	74·36
		100·00

S. Sheldon has carried out a number of experiments to determine the electric conductivity of copper when annealed at various temperatures. A sample of copper was drawn several times without annealing, so as to become very hard, and was then cut up into different lengths which were separately annealed at different temperatures both in a vacuum and in hydrogen, and tested for conductivity. The effect of the different annealings in vacuo in relation to conductivity is shown by the following figures; the conductivities of the samples were calculated from measurements of resistance, length, weight, and specific gravity :—

[redacted]

TABLE VII.

Annealed in a Vacuum.		Annealed in Hydrogen.	
Annealing temperature.	Conductivity.	Annealing temperature.	Conductivity.
°C.	Per cent.	°C.	Per cent.
20	101·5	20	99·0
37	101·5	45	99·0
54	101·5	105	99·3
118	101·6	234	99·8
215	102·0	360	101·0
300	102·1	483	101·9
600	102·4	1050	89·33
755	102·7	—	—
930	99·0	—	—

Cost of Depositing Copper.

According to Dr. Kiliani, the back E.M.F. is 0·12 volt, which has to be overcome with each pair of electrodes in the electrolyte under normal conditions. This back E.M.F. is due to the polarisation at the surface of the anode, and increases with the impurity of the raw copper used.

The following figures give the approximate cost of producing electrical energy on a large scale with condensing engines, the cost per kilowatt-hour working out to ·3995, in which case the cost of the electrical energy required to deposit one ton of copper is 14s. 5d. A large installation of 10,000 H.P. is now being put up near Manchester, which will supply electricity *at ½d. per kilowatt* :—

ESTIMATED COST OF WORKING A 2,100 KILOWATT PLANT, THE PRICE BEING BASED ON THAT PREVAILING IN ENGLAND.

(Staff arranged in three shifts for continuous running of 150 hours per week.)

			£ s. d.		£ s. d.
Stokers	6	at	1 13 3	per week	9 0 0
Trimmers	3	„	1 4 6	„	3 13 6
Engine-drivers	6	„	1 17 6	„	11 5 0
Oilers	12	„	1 8 0	„	16 16 0
Dynamo and switchboard hands	6	„	1 8 0	„	8 8 0
Superintendent	1	„	4 0 0	„	4 0 0
Total wages per week					£53 2 6

(At 150 hours = 7s. 1d. per hour.)

PER KILOWATT-HOUR.

	Pence.
Salaries and wages	·0405
Coal, 2·4 lbs. at 16s. per ton	·2050
Water, at 6d. per 1,000 gallons	·0014
Oil and sundry stores, waste, etc.	·0400
Standing charges, office expenses, rent, insurance, etc.	·0300
Repairs	·0100
Interest on capital £29,000 at 5 per cent.	·0222 *
Interest on buildings £5,000 at 5 per cent.	·0038 *
Depreciation on plant 10 per cent....	·0443 *
Depreciation on buildings 3 per cent.	·0023 *
Total cost per unit generated	0·3995d.

* On basis of working 50 weeks in the year.

The Anaconda Mining Company has recently made public the cost of electrolytic refining during the year 1897 to 1898 at its works at Anaconda, Montana; the figures given are as follows:—

	£	s.	d.
Assay expenses and salaries	3,062	7	8½
Electric light	475	11	11
Expenses	775	16	2
Labour	28,408	13	2
Legal expenses	426	7	1
Power-house expenses, coal	27,589	0	8½
„ „ labour	9,880	9	10
„ „ machinery and repairs	4,020	19	7

[redacted]

Making a total of £42,812 6s. 6d. for power, of which £1,250 was charged to silver mill, leaving a net expense of £41,562 6s. 6d. for power for the electrolytic refinery.

	£	s.	d.
For recasting scrap-anodes	3,585	4	8
Regenerating plant expenses	2,400	5	0½
Salaries, including management	3,252	9	11¾
Stable expenses	301	17	6
Sundry supplies	2,362	6	6
Switching product	181	5	0
Taxes...	1,146	10	3
Repairs on buildings	1,070	8	5
„ on machinery	1,521	0	11
On refining tanks	1,650	2	1¾
Making a total of...	£92,398	7	11¾

The output of electrolytic copper was 50,505,711 lbs., consequently the cost of production was 3s. 1½d. per cwt. or £3 2s. 6d. per ton.

In the above calculations the dollar was taken at 4s. 2d.

The PRESIDENT: We have had a communication from an honorary member, Mr. Henry Wilde, which I will ask the Secretary to read. The President.

Mr. HENRY WILDE, F.R.S. [*communicated*]: I have read with much interest the paper of Mr. Cowper-Coles on "An Electrolytic Centrifugal Process for producing Copper Tubes." May I point out that the process described is identical with the one patented by me in 1875 (No. 4,515), which has been in successful operation in Manchester and elsewhere for more than twenty years. By the publication of his paper Mr. Cowper-Coles has, however, rendered an important service to the electro-metallurgical industry in exposing the fallacy of submitting electro-deposited surfaces to the friction of foreign substances during the process of deposition. His paper also contains some interesting information on the electro-metallurgy of copper which is not readily available in other publications. Subjoined are extracts from the Specification and Claims of the Patent referred to:— Mr. Wilde.

"Whereas attempts have been made from time to time to substitute iron rollers covered with a thin layer of copper by means of electricity, for the solid copper rollers used in calico-printing and in other processes, but owing to the expense of the battery power and the slow rate at which the copper was deposited in the reguline state, such attempts have not hitherto been commercially successful.

"Now my Invention consists in giving to the electrolyte or depositing liquid in which the roller to be coated is immersed, or to the positive and negative electrodes themselves, a rapid motion of rotation in order that fresh *particles of the* electrolyte may be brought

Mr. Wilde. successively in contact with the metallic surfaces. By this means powerful currents of electricity may be brought to bear upon small surfaces of metal without detriment to the quality of the copper deposited, while the rate of the deposit is greatly accelerated (page 4).

"Instead of producing the whirling motion of the electrolyte by the rotation of the roller *b*, as above described, it may be produced by the rotation of the positive electrodes *g* mounted on a revolving frame, or by paddles revolving in the annular space between fixed electrodes and a fixed roller (page 5).

"This invention may also be applied to the electrolytic method of refining copper described in the Specification of Letters Patent granted to J. B. Elkington, November, 1865, No. 2,838" (page 4).

"CLAIMS.—First : Imparting a rapid whirling or rotating motion to a depositing solution in the manner and for the purposes described. . .

"Lastly : The application of the whirling or rotatory motion of the electrolyte in the refining of copper and the apparatus for effecting the same as shown and described."

Mr. Mordey. Mr. W. M. MORDEY : I should like to suggest to Mr. Cowper-Coles to add to Table 7 (on p. 277) a column indicating resistance. We all know what ohms are, but I think a very few of us know what mhos are.

Mr. Ferranti. Mr. S. Z. DE FERRANTI : About six or seven years ago I saw in Paris a process almost identical with that described by Mr. Cowper-Coles. It was not being worked commercially, but in a laboratory for the purpose of demonstration with a view to selling the patents. It was specially arranged for depositing a very thin and uniformly good plate at a very high current density. The difference was that the roller was horizontal instead of vertical, and the cylinder was only half covered with the electrolyte. The cylinder was a fairly large one, I think about 2 ft. 6 in. to 3 ft. in diameter, and was revolved very rapidly ; in fact, there was a great tendency to throw the solution about, and baffles had to be used to prevent the liquid being scattered over the room. I do not know what the peripheral speed was, but it was very high. The copper sheet deposited upon the metal mandrel was beautifully smooth and regular when stripped off. The patentees thought that the special point in the invention was not the high speed of rotation, but the power to produce cheaply a very thin copper sheet, which is an article sold in the market for many purposes at a very high price per pound.

I have also seen another application, somewhat similar to the one which we have seen this evening, of rotary deposit without burnishing ; it was produced by Mr. R. D. Sanders at Eastbourne, who, was, I believe, at one time the manager of the Elmore works. In his case he coiled a wire spirally upon an insulating cylinder. This mandrel was three parts immersed in the copper sulphate and rotated at about 100 revolutions per minute. He found that he could use a very high current density, and obtained a most beautiful spiral deposit of copper on the wire which grew until it was large enough to be uncoiled from the mandrel. The wire was then drawn down through a few dies and produced most beautiful results. I thought, and still think, *very* highly of that process. It has not, however, been applied com-

mercially in this country because of the prevailing idea that it is not possible to produce copper wire more cheaply by this method than by the old-fashioned method. The prevailing feeling is that we have got down to absolutely the bottom in the way of cost price, and that therefore nothing else can be cheaper. These are two applications of centrifugal depositing processes which, so far as one can see, are very much like the one that has been shown to us by Mr. Cowper-Coles this evening, and are both of them most successful in accomplishing the result for which they had been invented. Mr. [illegible]

Mr. G. L. Addenbrooke: I should like to ask Mr. Cowper-Coles if he would kindly tell us in what particulars his process differs, beyond the fact that the force used is centrifugal, from that described by Mr. Swan at the Royal Institution some time ago, in the lecture to which Mr. Cowper-Coles refers in referring to the smoothness of the deposit being dependent on the absence of solid particles. I remember Mr. Swan had a number of plates in which a copper deposit was produced by moving them at a very rapid rate in the solution, and showed how that motion led to the production of a perfectly even deposit, and permitted the use of a very great current density. Mr. Addenbrooke.

The President: There was one thing which interested me exceedingly in Mr. Cowper-Coles' description of his process. It was the account of the difference in conditions under which were produced the rough and granular, or nodular, deposit and the very smooth deposit, of which illustrations are shown in Figs. 4 to 12. He told us you might whirl the mandrel round at a relatively low speed without producing much effect, but that there was a critical speed at which an improvement in the state of the deposit occurred. He did not tell us what that limit was. Can it be given as surface speed in feet per second? I notice that some deposits are described as having been made at a peripheral speed of 500 feet per minute; but the question is, what is the peripheral speed at the critical point, and can the author give us any idea as to what is the physical meaning of the existence of this critical speed? The President.

With regard to the point raised as to conductivity, it may be known to some present that a Committee has been at work putting together the information that exists as to the conductivity of standard qualities of copper, obtained from a number of sources with a view to establishing authoritatively what is the standard of purity of copper. We are supposed to be working nowadays to Matthiessen's standard of 1862, but I am afraid none of the actual samples that are supplied to Matthiessen's standard are exactly the same as his standard was; and we have in the report of that Committee—which, by the way, will appear in full in our January Journal [this vol., p. 169]—these facts put before us and brought up to date. But in that case there are given not only the absolute values of the specific resistances of the copper, but also their values in terms of conductivity, Matthiessen's standard being regarded as 100 per cent. In 1862 it was supposed that Matthiessen had completely purified his copper, and that the absolutely pure copper which he produced would have a conductivity of 100 per cent., the highest that could be. Nowadays we have coppers with a conductivity of 102 per cent. as compared with that old standard. I think

The President. there are some reasons for preserving the standard in terms of conductivity, though I agree with Mr. Mordey that it would be an advantage to have the absolute resistances set down in ohms also by the side of the conductivity. Perhaps Mr. Cowper-Coles can give us some further information on this point as to what is the standard that he takes when he gives us certain things as having a conductivity of 102 per cent. Does he mean 102 in terms of the so-called Matthiessen's standard, or what does he mean?

Mr. Williams. Mr. ALAN WILLIAMS [*communicated*]: In the introduction to Mr. Cowper-Coles' very interesting paper the author has referred to a process now being worked on a large commercial scale in which a sheepskin burnisher and a fairly rapid rotation of the cathode are employed in order to obtain an even deposit of copper. In his description of the process he suggests that the effect of the burnisher is to apply an insulating coating to the projecting parts of the deposit, allowing the surrounding depressions to be filled up. I have had an opportunity of seeing this process at work, and can testify to the excellent deposit produced by it.

I do not believe that the explanation given of the working of this process is the correct one, although it is, I understand, accepted by the parties working it. If the even deposit were produced through the deposition of an insulating film on the "nodules" it would seem that the "impregnators" would, after a short time, give up all the insulating grease they originally contained, and would then be no longer able to protect the "nodules." This, however, is not the case; the "impregnators" are quite as efficient at the end of a long run as at the start. Moreover, in the later patents referred to by the author "impregnators" are used free from excess of grease, which rather points to the fact that the grease is not of much importance.

My theory of this process and of all other processes which have produced satisfactory results is this: In an ordinary depositing cell, immediately the current is switched on, copper is deposited on the cathode, and a thin layer of electrolyte touching the cathode becomes very considerably weakened in consequence. Before more deposition can take place this layer of exhausted electrolyte must be removed.

If left to itself it will naturally break up in a sort of granular formation, being perforated at a number of points and allowing copper-bearing electrolyte to have access to the cathode through the perforations and permitting a number of "nodules" of copper to be formed. An irregular deposit then grows on these "nodules."

To prevent this action from taking place, it is necessary to remove the film of exhausted electrolyte immediately it is formed, either by friction, violent circulation of the electrolyte or rotation of the cathode. Consequently the process which most effectually removes this film, and which at the same time gives the most uniform distribution of current and the most uniform strength of electrolyte over the whole surface of the cathode, should be the one to produce the best deposits of copper and to allow the highest current density to be used.

Mr. Gibbings. Mr. W. GIBBINGS [*communicated*]: Mr. Cowper-Coles' paper is of great interest, and will doubtless be specially appreciated by those

members who are connected with Electro-Metallurgy, a subject which does not engage the attention of the Institution so largely as other subjects. Mr. Gibbings.

The centrifugal process of making copper tubes, etc., will not, I think, be found to be new, for a similar, if not the same, process was patented in February or March, 1894, by Paul David, and was taken over and used by La Société des Cuivres de France, 3, Rue Cambon, Paris. The centrifugal process in this patent is claimed "pour fabrication de tubes et autres objects en cuivre par simple rotation dans un électrolyte." However, whether Mr. Cowper-Coles has been anticipated or not, he deserves great credit for working out the process independently. I think this process is in advance of others invented for like purposes, but I do not think any electrolytic process yet invented for making tubes is, or is likely to be, a commercial success. These remarks apply equally, or with greater emphasis, to the electrolytic manufacture of wire. Certainly we are very far from the "revolution in the copper industry" which the Elmore process promised twelve or fourteen years ago, and the "considerable success" spoken of by the Author of the paper as having been attained by this process has not yet been realised by the shareholders.

The method of projecting the electrolyte on the cathode was tried at Anaconda, and abandoned.

I notice the centrifugal process is claimed to do away with the lamination trouble. If it does, it has overcome one of the great difficulties met with in the direct manufacture of tubes and sheets by electrolysis, but it is only one ; there are many more between theory and commercial success.

The Temperature-Resistance-Curve, given on page 263, requires explanation. The great drop in resistance between 60° and 80° F. is not due to temperature *per se*, but to the fact that in the solution experimented on the copper sulphate crystallises out at 75° F. This is the temperature of solidification, assuming that the acid used was 168 twaddell. If the acid used in the experiment was of lower specific gravity, crystallisation would occur at a rather lower temperature.

This will also suggest itself as the explanation of the curves on page 259, but as an analysis of the solution used in this case is not given, I cannot determine the point of crystallisation.

"Best resistance" on page 267 should apparently read "least resistance."

Table VII., with results of experiments to determine conductivity of copper annealed in a vacuum and in hydrogen shows remarkable results, but not such as are, as far as I can see, of any practical value. The annealing of copper in hydrogen, even if it could be done on any large scale, would render the metal totally unfit for rolling or drawing.

Mr. Cowper-Coles, in reply, said : With reference to Mr. Henry Wilde's communication, undoubtedly there is now nothing new in revolving a cathode, as this was done by him twenty-five years ago. I myself have used revolving cathodes for ten years or more. What, however, I claim to have discovered is, that if the cathode is revolved at a sufficiently high speed so as to *generate* an appreciable amount of centri- Mr Cowper-Coles.

Mr. Cowper-Coles. fugal force, remarkably smooth deposits can be obtained at very high current densities. I have also observed that there is a critical speed at which excellent copper deposits can be obtained, which cannot be obtained at any other speed. I am well acquainted with Mr. Henry Wilde's patent in which he claims, "imparting a rapid whirling or rotating motion to a depositing solution either by revolving the electrodes or by means of paddles," but I was not 'aware that he had discovered that by rotating the cathode at a certain speed smooth deposits of copper could be obtained at remarkably high current densities, even when a very large percentage of free acid is present in the electrolyte.

With reference to Mr. S. Z. de Ferranti's remarks on the process he saw in Paris, this evidently is not a practical one. In the first place, only half the cathode is immersed in the electrolyte, and therefore a plant to give a large output is very cumbersome and the action obtained with a horizontal cathode is not the same as that obtained in the process I have described. With reference to Mr. R. D. Sander's process for making copper wire, I have heard of this process, and I quite agree that such a process would not compete in price with the present method of wire drawing.

In reply to Mr. G. L. Addenbrooke's remarks, I have not read the paper Mr. Swan delivered before the Royal Institution, but I have talked to him on the subject of his paper, and understand that all the experiments he made were with horizontal anodes, and that the difficulty he experienced was that when a high speed was used deep lines were formed on the cathode. This has also been my own experience, as I have tried to produce parabolic reflectors by revolving the cathode at a high speed, at the same time using a high current density, but found it impracticable, as the lines of rotation spoilt the reflecting surface, and the speed of rotation had ultimately to be reduced to about five revolutions per minute.

With reference to the President's remarks, as regards the critical peripheral speed, this should not be less than one thousand feet per minute. The centrifugal process enables a very high percentage of free acid to be used, which is advantageous both from an electrical and from a copper refining point of view. The electro-motive force required is less, and the large percentage of free acid enables ores to be leached which it would not be possible to leach if only a small percentage of acid were used.

[*Added, February 24th.*]—I should like to state, in reply to Mr. W. Gibbings' communication, that the process he refers to is evidently a similar process to that of Mr. Henry Wilde, to which reference has been made above.

The President. The PRESIDENT: It is now our pleasing duty to return our thanks formally to Mr. Cowper-Coles for the paper which he has been good enough to bring before the Institution. We do not often have a paper at this Institution on electrolytic processes, and when we have one it is well that we should recognise the importance of this branch of the electrical industry. May we hope to have other papers on electro-metallurgical subjects as time goes on! Anything that will produce a purer or cheaper copper, or a copper that is more mechanically good

[redacted]

than we have had before, is so much to the good and benefit of the electrical industry as a whole, that I think we may congratulate Mr. Cowper-Coles, while we thank him for the paper which he has given. The President.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members :

Charles A Burge.
George Cheetham.
Herbert Sydney Russell, B.Sc.
John Julius Steinitz.
John Macintyre, M.B., M.Ch., F.R.S.E., &c.

Associate Members :

Captain Cecil William Davy, R.E.
Hugh Frederick Dawson Jacob.
Lieut. George Stuart Knox, R.E.
James McCaffery.
J. E. Douglas Neale.
Joseph John Smith.
Charles Edgar Williams.

Associates :

William Henry Ashman.
Edward Arthur Barker.
Robert Leopold Bendall.
Richard George Botting.
John Edward Dawson.
Walter Bawcutt Edmunds.
Alexander McAra Fyfe.
Edward Garton.
John Bertram Gibbons.
David Henriques.
John Murray Hincks.
Albert Thornley Kinsey.
Henry J. Lewenz.
Selby Lennox Macfarlane.
William Norman Price.
Frederick William Rayner.
Albert Edward Salisbury.
Harold Sandwith.
Sydney George Starling.
George Stannage.
Robert Martill Wilson.

Students :

Harold J. Brooke.
Mortimer Arthur Codd.
Emil Samuel Conradi.
Ernest Salomon Lance.
John Bernard Langford.
John Milton.
Christopher Stewart.
Harold Dalrymple Symons.
Cyril Frederick Thatcher.
Albert Isaac Tracey.
Rupert Harold Waite.
John Warrack.

ELECTRICAL TIME-SERVICE.

CONTINUATION OF DISCUSSION ON THE PAPER BY F. HOPE-JONES.

Mr. Puttkammer

Mr. C. PUTTKAMMER [*communicated*[1]]: In his paper, Mr. Hope-Jones omitted to refer to the work of the Normal Time Company (Gesellschaft Normal Zeit), which, since the year 1894, has been working in Berlin a system, whereby all clocks connected with their central station have been regulated and have been provided with all the contrivances which would, in the opinion of the author of the paper, constitute the ideal of an organisation of this kind in London. The Company has already established 5,000 connections in Berlin alone, including all the State buildings, and, in fact, all the establishments in which it is necessary to keep correct time. The technical points of the system are not, however, entirely in accord with Mr. Hope-Jones' views.

The principle hitherto followed in the synchronisation of "Independent Electric Clocks" (see p. 121, Class *2a*) has been to regulate the working of the clocks about once a day. The clocks which the author classes as *2b* have no independent clockwork; but the hand is moved forward a certain space by electric current at short intervals. In neither system is it possible to ascertain, in the event of disturbance or interruption, whether the current really fulfils its function or not. If the circuit becomes disconnected, the clock referred to in Class *2a* will continue to go, as if nothing had happened, whilst the regulating contrivance will cease to act, and there is always the risk of some mishap occurring, whilst the customer remains under the impression that his clock is right. In Class No. *2b* the clock will simply stop until the fault has been repaired. But in either case it is necessary to notify the central station of the disturbance. This was also the reason why previous undertakings have failed to attract the confidence of the public.

The Paris organisation of Popp has thus failed up to the present to form an extensive connection, and the concern started by the Allgemeine Electricitäts Gesellschaft proved a failure.

The Normal Time Company is the only concern which has hitherto succeeded in achieving good results in this direction. This Company started on the principle that it is not sufficient merely to regulate and wind up the clock, but that the main point is to exercise a permanent control over the correct working of the time-pieces connected with the central station. A time-piece continually regulated from the observatory by the Jones system exercises regular control over the clocks connected by it by means of a current entering the circuits at certain intervals and being cut off after a given time. The clocks are switched on to these circuits at certain times appointed accurately beforehand, and, in their proper order, receive the regulating current and are then switched off again, whereupon the next clock becomes switched on and so forth.

[1] Received too late to be included in the account of the discussion on this *paper* (vide this Volume, pp. 119–153).

Mr. Puttkammer

The clocks are regulated through the central time-piece, and are wound up electrically either by a strong current (System of Professor Aron) or by a weak current (Normal Time System). The principal point consists, however, in a registering contrivance affixed to the central time-piece, on which every clock registers a mark at the moment it is connected with the circuit by means of an electro-magnet with a pointed lever making a record on a running strip of paper. From the position of this record the official in charge can always tell to a second how great the deviation in time of the clock in question has been, and whether the fault has been remedied; if this is not the case, and if an interruption of any kind should have occurred between the connected clock and the central timepiece, it will at once become evident to the officials at the central station through the position of, or the non-appearance, of the mark, and they will know that an accident has happened between the central station and the clock in question, and will so be in a position to remedy the defect at once. As the connected clock is switched on several times during the twenty-four hours, deviations cannot be very great. Another advantage of the system is that the central station can observe and regulate most frequently those clocks which it is especially important to keep correct. The Normal Time Company has not limited its activity to a single city, but has distributed its efforts over the whole of Germany, the Royal Observatory giving the Company the correct time, and the latter, in its turn, giving it to its customers. Thus, for instance, it has made an arrangement by which a specially constructed clock sends out the exact time automatically, every morning, through the telegraph wires, to the most distant parts of the country; and also one by which the nautical time-balls in the ports are automatically regulated from a central station. An arrangement of this kind has been established in the port of Bremen under the special supervision of the Postal authorities during the last three years. The clock, which is regulated from Berlin, has never during the whole of this period deviated from the correct time by more than two-tenths of a second. The ball has not, however, repeated this error of two-tenths of a second, as the current working the same passes through a special checking contrivance, by which the small error is automatically neutralised.

Mr. Hope-Jones

Mr. F. HOPE-JONES [*communicated, in reply*]: I have read with interest Herr Puttkammer's account of the synchronising methods employed by the Gessellschaft Normal Zeit of Berlin, and regret that it was impossible in the short space at my disposal to consider Class 2*a* at greater length and to review the many methods that have been suggested for indicating at a central time station the condition of the clocks operated upon. But the provision of all the contrivances he describes do *not* constitute my ideal of an organisation of this kind in London. To my mind a house-to-house time-service to be really successful must be above all things simple. I am convinced that no system has a chance of remunerative adoption in this country which requires: (1) Independent time-measuring mechanisms wherever clock faces are desired, (2) a method of synchronising these at the dictation of a master clock, and (3) a method of indication at headquarters to report to what

Mr. Hope-Jones.

extent No. 1 has succeeded or failed in its duty of measuring time, and also to what extent No. 2 has succeeded or failed in its duty of correcting No. 1. Surely such a system savours too much of the accumulation of automatic devices superimposed one upon another to correct evils but not to cure them.

I do not, however, ignore the advantages of "reporting" systems; indeed, I advocated them in a contribution to an electrical journal some years ago, and I have no doubt that the method described by Herr Puttkammer, in which each clock in turn imbibes synchronisation from a common circuit, is an excellent one, but I submit that in Berlin they begin with the wrong thing, and consequently require a most elaborate system to keep it to time.

I would begin with one-wheel electrically propelled dials, and arrange the mains and sub-circuits in such a manner that a disconnection or other electrical fault would be apparent in the central station. In cases where large circuits and heavy responsibilities require it, automatic methods of reporting the accuracy of the dials might be applied.

Experiment.	Position of section O and Connector to Ring 1	Generator Contact-Maker reads	Amperes.			Amperes.		
			A	A_1	A_2	Ar_a	Ar_b	Ar_c
1	120°	40·2	66·2	+40	−59·5	+42·8	−16·6	+23
	141°	45·6	70·7	+66·5	+42	−23·1	−18·6	+47
	162°	42·3	66	+80	−24	+6·5	−17·5	+62
	189°	37·5	64·3	−75·5	−6·5	+66·6	−8·8	−2
	210°	34·2	64·3	+60	−38·5	+42·9	−17·1	+21
	231°	30·9	66·6	+41	−66	+22·3	−18·7	+47
	252	27·3	70·7	+22·5	−80·5	+6·3	−16·1	+64
	279°	22·8	66·5	−7·0	−76·5	+67·9	−8·5	−1
2	120°	43·5	42·6	+71	14	−7·2	−21·2	+40
	141°	40·2	40·7	+71	−4	−17·2	−13·2	+57
	162°	36·6	36·6	+61	−24·5	−24·3	+9·1	+61
	186	32·1	38·2	+35	−56	+8·6	−26·4	+26
	210°	28·5	41·6	+14	−72	−8·2	−22·2	+49
	231°	25·2	40·7	−5	−72	−18·2	−13·2	+58
	252°	21·9	36·9	−24·5	−60	−23·7	+0·7	+60·7
	279	17·1	38·0	−56	−34·5	+8·2	−26·2	+29
3	120	53·1	60·1	−11	+85	+78	−7	−18
	141°	46·5	63·3	+27·5	+75	+55·4	−19·6	+7
	162°	46·2	65·4	+61	+61	+32·7	−28·3	+32
	189°	41·7	63·3	+86·5	+41	+95·3	+8·9	−32
	210°	38·1	61·2	+87·5	+14	+81·3	−6·1	−20
	231°	34·5	65·4	+76	−26	+57·7	−18·3	+7
	252°	31·2	64·3	+62	−59	+33·6	−28·4	+30
	270°	26·7	62·2	+40	−81	+91·6	+10·6	−2

eral of ster, ssor hair. on the list een ate e. ated bers. oving avel, usly accorded.

The PRESIDENT: I have an announcement to make to

TABLE II.

Arc *a*.				Arc *b*.				
Resist-ance in Ohms.	Volts due to Current.	Watts due to Current	Volts per Section due to Current.	Resist-ance in Ohms.	Volts due to Current.	Watts due to Current.	Volts per Section due to Current.	Resis-ance Ohm
·014	·599	25·6	·068	·042	— ·697	11·6	— ·027	·028
·024	·554	12·8	·037	,,	— ·794	15	— ·030	·018
·034	·221	1·4	·010	,,	— ·735	12·9	— ·028	·008
·004	·266	17·7	·106	,,	— ·370	3·2	— ·014	·038
·014	·509	25·6	·069	,,	— ·718	12·3	— ·027	·028
·024	·535	11·9	·036	,,	— ·785	14·7	— ·030	·018
·034	·221	1·4	·010	,,	— ·676	10·9	— ·027	·008
·004	·272	18·4	·109	,,	— ·357	3·0	— ·014	·038
·014	— ·101	·7	— ·011	·042	— ·890	18·9	— ·034	·028
·024	— ·413	7·1	— ·027	,,	— ·554	7·3	— ·021	·018
·034	— ·820	20·1	— ·030	,,	+ ·004	0·0	+ ·000	·008
·004	+ ·032	·3	+ ·014	,,	— 1·100	20·3	— ·042	·038
·014	— ·115	·9	— ·013	,,	— ·93	20·6	— ·035	·028
·024	— ·437	7·9	— ·029	,,	— ·554	7·3	— ·021	·018
·034	— ·800	10·1	— ·038	,,	+ ·020	0·0	+ ·001	·008
·004	+ ·033	·3	+ ·013	,,	— 1·10	28·8	— ·042	·038
·014	1·00	85	·12	·042	— ·20	20·5	— [illegible]	·028
·024	1·33	73·7	·00	,,	— ·82	10·1	— ·031	[illegible]
·034	1·11	80·3	·05	,,	— 1·10	33·7	— ·045	[illegible]
·004	·88	80·2	·15	,,	+ ·37	3·3	+ [illegible]	[illegible]
·014	1·14	[illegible]	·13	,,	— ·26	[illegible]	— [illegible]	[illegible]
·024	1·48	[illegible]	·00	,,	— [illegible]	[illegible]	— ·026	[illegible]
·034	1·14	88·8	·05	,,	— 1·10	33·8	— ·045	[illegible]
·004	·87	88·0	·15	,,	+ ·44	4·7	+ ·017	[illegible]

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

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[T]he Three Hundred and Forty-first Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday evening, February 8th, 1900—Professor SILVANUS P. THOMPSON, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on [Ja]nuary 25th, 1900, were read and approved.

The names of new candidates for election into the [I]nstitution were announced, and it was ordered that the list [s]hould be suspended in the Library.

The following transfers were announced as having been [a]pproved by the Council—

From the class of Associates to that of Associate Members:—

Walter J. Belsey.	George Douglas Collins.
J. F. M. Bennett.	Victor Jacques Delebecque.

Charles Stirling.

From the class of Students to that of Associates—

Alfred Norman Dixey.	Sydney Richard Inch.

John Henry Johnson.

Messrs. A. E. Levin and S. J. Clay were appointed [s]crutineers of the ballot for the election of new members.

A donation to the Library was announced as having [b]een received since the last meeting from Mr. J. E. Petavel, [t]o whom the thanks of the meeting were unanimously [a]ccorded.

The PRESIDENT: I have an announcement to make to

the Institution which shows us that our late Past-President, Professor Hughes, bore us in mind even to the last, he having left us a bequest in his will. I have received a letter from Mr. Christmas, who was his solicitor, dated February 6th, enclosing the following extract from the will :—

"I direct and declare that the Legacy of Two Thousand pounds so bequeathed to the said Institution of Electrical Engineers, of which I am Past-President, shall be invested by them in any manner for the time being authorised by Law for the investment of Trust funds for the purpose of founding in connection with that Institution a Scholarship Fund to be called the David Hughes Scholarship Fund. And I direct that the annual income produced by the investments for the time being constituting that Fund shall be given each year to a Student preparing himself for the career of an Electrical Engineer under conditions similar in all respects to those under which the Fund now known as the Sir David Salomons Scholarship Fund is administered, but so that if and so often as for any reason the Scholarship hereby founded shall not be for any given year awarded to any Student, the annual income of the Fund for that year shall be invested in manner aforesaid and added to the Capital of the David Hughes Scholarship Fund."

On receipt of this letter I acknowledged it to the solicitor in the name of the Institution, and I am sure you would wish to join with the Council in sending a formal expression of grateful acceptance by the Institution to the Executors of our late Past-President.

The Secretary will now read the list of Officers and Committee elected by the Newcastle Local Section of the Institution at their last meeting.

The Secretary read the list as follows :—

OFFICERS AND COMMITTEE OF THE NEWCASTLE LOCAL SECTION.

Chairman—A. W. Heaviside.
Vice-Chairman—W. D. Hunter.

Committee.

C. Burnet.	J. A. Jeckell.
H. F. Friedricks.	W. C. Mountain.
J. H. Holmes.	The Hon. C. A. Parsons.

Hon. Secretary—J. F. C. Snell.

THE STANDARDISATION OF ELECTRICAL ENGINEERING PLANT.

By R. PERCY SELLON, Member.

To the user of electrical engineering plant, not less than to the producer, the subject of its standardisation is one of great practical importance.

By "standardisation" is meant the general acceptance, to a far greater extent than at present obtains in this country, of certain standards of output, quality, efficiency, or other characteristics of electrical engineering plant, to meet ordinary requirements of usage for light, traction, and power.

1. Of the four chief ingredients of successful competitive production, viz.: (*a*) cheap labour (not to be confounded with low wages); (*b*) cheap materials; (*c*) efficient management, and (*d*) repetition manufacture, much has been said and written of the first three, but little of the last. And yet every manufacturer of experience knows that it is as influential a factor in determining not only his own profit, but decisive advantages to the user, as any of the factors of labour, materials, or supervision. In order to convince oneself of this, it is only necessary to consider the influence of repetition manufacture upon the price and reliability of any article of common use,—say, in our own industry, incandescence lamps and their accessory fittings, in respect of which some measure of standardisation has been evolved; and to reflect what, on the other hand, the cost would be if many manufacturers or users adopted different standards.

In the early years of an industry, experiment and development by trial and error are desirable and inevitable in order to ascertain the possibilities and limitations of the art. But as the stage of repetition public demand is reached, standardisation becomes increasingly possible and advantageous.

Its advance is, however, liable to be retarded by a number of causes, notable among which are the folly of some producers, and the ignorance of many users.

There are always some manufacturers who think that by supplying a special or unique type of apparatus to the buyer they will force him into placing his future orders with them. Hence they resist any tendency towards standardisation.

There are also many buyers who allow themselves to be

persuaded into the belief that in securing something new and different from previous usage they are doing well for themselves and giving evidence of superior intelligence: whereas the probability is that they are paying a higher price for a less reliable article.

There is a third class who believe that standardisation is the business of the producer only: and that the user need not concern himself to assist in bringing about a condition of things for which every manufacturer who knows his business eagerly strives. This view is erroneous.

The intelligent producer is undoubtedly deeply concerned in the advent of standardisation; because it means for him the possibility of repetition manufacture—on the manifold advantages of which it is not necessary to dwell.

But to the user, if he would only realise it, the fruits of standardisation are equally beneficial; for they involve for him the following advantages:—

(*a*) Less capital outlay.
(*b*) Prompt delivery.
(*c*) Immunity from the risks attendant on novel designs.
(*d*) Full manufacturer's guarantees.

2. Viewed from the "patriotic" standpoint, this subject acquires also special significance in these days of acute struggle between British, American, and Continental manufacturers for our own and the world's markets in electrical wares.

The causes which underlie the ability of American and Continental producers to compete keenly and successfully with the British electrical manufacturer are several, and generally outside the scope of this paper. But conspicuous among them is the fact that the former have (as any one who has visited their leading workshops can testify) attained to a degree of repetition manufacture superior to the British producer.

This fact is so noteworthy as to constitute in itself a telling argument in favour of increased standardisation among us: for the flood of American electrical engineering plant into Great Britain is swelling in spite of the fact that we have the advantages of lower wages, (on the whole), cheaper materials, and a longer experience of factory organisation.

3. It therefore becomes important to endeavour to trace

the cause of this preferential position held by our foreign rivals. The explanation would appear to lie in a difference of procedure.

According to American and Continental practice the producer determines, in a large measure, the character of the plant employed by the user; while according to British custom the buyer very generally imposes upon the manufacturer not merely a specification of the ends he wishes to attain, but the details of means by which he desires those ends to be achieved.

This is due to the fact that under the American and Continental system producers largely secure outlets for their manufactures through the agency of powerful financial organisations created by and allied to their interests, who are concerned simply with commercial results, and are content to leave the technical means of attaining them to the manufacturing interests with whom they co-operate. In America these organisations take the form of colossal Trusts or consolidations of competing interests; on the Continent that of Industrial Banks. In either case there is a close relation between producer and buyer.

In Great Britain, on the other hand, the demand for electrical engineering plant in recent years has issued chiefly from local authorities, or from private users unconnected with any manufacturing interests; and these have very naturally had recourse to electrical engineers acting in a consulting capacity or passing permanently into their service, to guide them in the choice of plant to fulfil their requirements.

That the practical operation of this system in the past has been primarily responsible for the relative absence of standardisation in this country, with its attendant evils alike to user and producer, appears certain. For the user's engineer has frequently been out of touch with manufacturers; and the temptation to strike out on new and "showy" lines, suggestive of individuality, ability, or foresight, has, in the very nature of things, been great. The result has been the issue of specifications too often calling for wanton divergences from previous practice or existing manufacturers' standards.

The source of the evil is traceable to the fact that the buyer's engineer has gradually overstepped the rational

function of stating the ends or performance required by the buyer, and has proceeded to specify in minute detail the means or constructional methods by which the required results are to be achieved, without taking responsibility for the result.

It is not necessary to adduce specific examples in illustration of this statement, because the author believes that it is one which no fair-minded electrical engineer acquainted with the facts will dispute. There is no difficulty in producing overwhelming evidence of its truth if such be required.

To the same primary cause may probably be traced the variety in size and character of the power units in many of the central stations of Great Britain—another instance of "splendid isolation" in our methods; for foreign practice is at one in adopting fewer and larger units, uniform in size and character from the commencement. Whether advantages of temporarily reduced capital outlay and higher efficiency under our system are a sufficient compensation for loss of interchangeability and periodical relegation of plant to the old metal market, remains to be proved when the bills are presented later on and contrasted with one another. Meantime it is interesting to note that one result of our procedure is the comparative unpreparedness of British manufacturers to compete with foreign producers in the common markets of the world as regards large units.

4. Whether British collectivism is on the whole a more healthy medium than American or Continental private enterprise for the progressive growth of the electrical engineering industry is a large question outside the scope of this paper. We have here to accept it as a fact, and consider whether an evil which it has brought in its train is a necessary one; and if not, how it can be averted for the future.

Assuming, then, that the buyer's engineer has come to stay, it would appear that a condition precedent to the standardisation of plant is the standardisation of the buyer's engineer.

The fundamental fact requiring appreciation is that standardisation, to the greatest degree possible, is in the interest of the user at least as much as that of the manufacturer,

From this we may pass on to postulate that standardisation is primarily the function of the producer and not of the user or his engineer, because the former is in a better position to determine, experimentally and by his more intimate knowledge of the means of production, the direction and extent to which it is possible. Inasmuch as the manufacturer's success is dependent on the judgment with which he creates or responds to public demand, there exists always an efficient safeguard that he will not (consciously) standardise on unsuitable or inefficient lines.

The user, on the other hand, is of course the proper judge as to the results he wishes to achieve.

It would appear, therefore, that the initial obstacle to a greater measure of standardisation than at present obtains would be removed if the user or his engineer would confine himself to stating the ends he has in view, leaving it to the producer to furnish the means whereby they may be attained.

If this procedure were adopted, users would still retain full liberty of choice between the products of different manufacturers, while the latter would have an opportunity (which under the present system of detailed specifications they do not enjoy) of undertaking repetition manufacture, assuming that they have sufficient confidence in the substantial harmony between their designs and public requirements to take the risk of quantitative production.

This system would have the incidental advantage that the producer could then be properly called upon to guarantee results, since the responsibility of selecting the means to attain them would rest exclusively with him. The present custom too often imposes upon the manufacturer a mass of fantastic detail emanating from the brain of the user or his engineer, for which he is called upon to take responsibility: an illogical system which can only be compared to the proposition that every man should be expected to father another man's child.

It may be objected that the general adoption of the course suggested would lead to stagnation in development, and that the producer, relieved from the constant pressure of change now exerted by the user, would settle down to the perpetuation of antiquated designs—to the disadvantage of the public and the fetish of Progress. The answer to this is, firstly, that much of the change hitherto

[illegible]

[illegible] be acceptable to the [illegible] higher price for an [illegible] effectively guaran- [illegible] advantage to pro- [illegible] standardisation be confined [illegible] performance, and not to means or constructional detail.

Under the term "ends" or "performance" as opposed to "means" or "constructional detail" would fall the following:

(*a*) Steam pressure.
(*b*) Electrical pressure of generation.
(*c*) Electrical pressure of distribution.
(*d*) Periodicity of alternate current generation.
(*e*) Sizes of generating steam units—(say in convenient fractions or multiples of horse-power or kilowatts).
(*f*) Sizes of mains (say in convenient fractions or multiples of a square inch or other unit).
(*g*) Sizes of motors ;

and similarly as regards transformers, arc and incandescence lamps, and essential fittings and accessories.

That much can be done in this direction is evidenced by the ease and rapidity with which, as regards electric traction, we have acquiesced in the standards of pressure, general construction, and types of motors, trucks, and accessories, prevalent in America. There can be little doubt that had practical electric traction originated with us, instead of being an imported art from the United States, we would still be in the stage in which buyers' engineers would be creating different "standards" of their own composing, while every producer would be expected to manufacture and guarantee a corresponding variety of designs.

The author understands that most of the leading electric cable manufacturers in this country have already adopted, by agreement among themselves, certain standards in their own department of production. The question of standardisation has also for some time received attention at the hands of the Electrical Engineering Plant Manufacturers' Association. Again the Municipal Electrical Association, a body thoroughly representative of the municipal user's interests, has given evidence of its readiness to co-operate with manufacturers in the direction of standardisation of the commercial conditions of contracts for electrical plant. Its representatives have met in conference representatives of the Electrical Engineering Plant Manufacturers' Association and have agreed upon certain general conditions as a basis for specifications of plant required by local authorities; and the outcome has undoubtedly been beneficial. It is evident, therefore, that the whole subject is ripe for consideration on the broader basis of harmonising, by adequate representation and discussion, all sections of users' interests with those of producers.

6. It is not possible to enter in this paper upon the consideration of the actual formulæ which might constitute standards for the future. This is a very large and important question demanding much careful thought and discussion. The machinery for this purpose already exists, at any rate as a nucleus, in the Uniformity Committee of this Institution, appointed shortly after the submission of a highly suggestive paper on "Uniformity of Plant," by Mr. C. H. Wordingham, before the Municipal Electrical Association in the summer of 1898. But beyond a word of advice on the subject of standard periodicities, nothing has so far issued publicly from the deliberations of this Committee extending over eighteen months. At this rate we may become irretrievably committed to many steps which all may live to regret, before effective results are obtained; for an unexampled expansion in every department of electrical engineering, notably those of electric traction and of power distribution over extensive areas, appears about to take place in this country.

The author ventures to suggest that additional weight and acceleration to the work of the Committee of the Institution would be given if it were strengthened by the addition of representatives of all interests concerned, viz., those of the manufacturer, user, consulting engineer, and user's engineer. The Institution might also encourage the submission of papers suggestive of standards for various classes of electrical engineering plant and accessories. These, together with the views which would be brought out in discussion, would serve as a valuable guide to a representative Committee.

In conclusion, the propositions which the author has endeavoured to establish may be briefly recapitulated as follows:—

(*a*) Standardisation, to a greater degree than at present exists, is in the interest of the manufacturer; as a means of facilitating repetition production and of meeting the competition of standardised foreign manufactures.

(*b*) Standardisation of "ends" or "performance" as distinct from "means" or "constructional details" is equally in the interest of the user; by securing for him low purchase cost, prompt delivery, freedom from the risks of experimental design, and full manufacturer's guarantees.

(*c*) The relative absence of standardisation in Great Britain, in contrast with other countries, is mainly traceable to the prevailing system wherein the user's engineer specifies "means" or "constructional details," instead of confining himself to "ends" or "performance."

(*d*) The determination of standards by organised effort, rather than by the slow and costly process of "trial and error," is desirable, and should be undertaken under the auspices of the Institution of Electrical Engineers, as representing the interests of both producer and user.

P.S.—The accompanying table of Central Stations in Great Britain, with particulars of system, periodicity, generating pressure, and distributing pressure employed, is adduced for the convenience of members.

Table showing System in Periodicity, Generating Pressure and Distributing Pressure in the Central Stations of Great Britain.

Name of Station.	System.	Periods.	Generating Pressure.	Pressure at Lamps.
		∿	Volts.	Volts.
Aberdeen	Direct Three-Wire	...	448	220
Aberystwith	Alternating ...	100	2,050	100 & 220
Alderley Edge	Direct Three-Wire	...	420–460	210
Altrincham	Alternating ...	80	2,000	100
Ashton-under-Lyne ...	Direct Three-Wire	...	440 Traction 550	200
Ayr	Alternating ...	60	2,100	100 & 200
Barking	Direct Three-Wire	...	460–500	230
Barnsley	Do.	...	450	230
Barrow	H. T. Continuous	...	1,100	220
Bath	Alternating ...	100	2,000	100
Bedford	Do.	60	2,000	100
Belfast	Direct Three-Wire	...	440–500	220
Bexhill	Do.	...	440	...
Birkenhead	Do.	...	460	230
Birmingham	Do.	...	...	110 & 220
Blackburn	Alternating ...	50	2,000	110 & 220
Ditto	Direct Three-Wire	...	230–250	110 & 220
Blackpool	Alternating ...	83	2,000	200
Bolton	Do.	83	2,000	100
Bournemouth	Do.	100	2,200	100 & 200
Bradford	Direct Three-Wire	...	250 & 500	230
Bray	Alternating ...	60	1,000	100
Brighton	Direct Three-Wire	...	300	115 & 230
Ditto	Alternating ...	70	2,400	115 & 230
Bristol	Do.	93	2,050	105 or 210
Burnley	Direct Three-Wire	...	220–240	220
Burton-on-Trent ...	Alternating ...	75	2,000	100
Bury	Direct Three-Wire	...	230	220
Cambridge	Alternating ...	90	2,000	100 & 200
Canterbury	Direct Three-Wire	...	440	220
Cardiff	Alternating ...	40	2,500	100 & 200
Charing Cross Co. ...	Direct Three-Wire	...	100 & 1,000	100 & 200
Carlisle	Do.	...	460	230
Chatham	Alternating ...	100	2,400	100
Chelmsford	Do.	100	2,100	100
Chelsea	Direct Three-Wire	...	...	100 & 200
Cheltenham	Alternating ...	93	2,200	100 & 200
Chester	Direct Three-Wire	...	440	210
Chislehurst	Do. Using Motor-Altr. and buying H.T. Energy	...	420	210
City of London	Alternating ...	100	2,000	100 & 200
Coatbridge	Do.	100	2,080	100
Colchester	Direct Three-Wire	...	220	105
Cork	Do.	...	500	230

NAME OF STATION.	SYSTEM.	PERIODS.	GENERATING PRESSURE.	PRESSURE AT LAMPS.
		∿	Volts.	Volts.
County of London ...	Alternating ...	100	2,100–2,200	100
	Direct	...	530	Power 510
	Alternating (2-phase	50	2,100–2,200	200
Coventry	Alternating ...	87	2,000	200
Croydon	Do.	60	2,000	200
Crystal Palace Co. ...	H. T. Direct ...	...	1,000–1,100	100
Darwen	Direct Three-Wire	...	460–500	230
Derby	Alternating ...	40	2,000	102 & 205
Dewsbury	Direct Three-Wire	...	250	110 & 220
Dover	Alternating ...	100	2,000	100
	Direct (Tramway)	...	500	500
Dublin	Alternating ...	83	2,100	100
Dundee	Direct Three-Wire	...	220	200
Ealing	Alternating ...	40	2,000	102
	Series D.C. Arc Lighting ...	...	1,800	100
Eastbourne	Alternating ...	83	1,800	100
	Series D.C. Arc Lighting ...	...	...	...
Eccles	Alternating ...	50	2,000	200
Edinburgh	Direct Three-Wire	...	...	115 & 230
	Alternating ...	50	2,100	...
Exeter	Do.	100	2,000	100
	Series D.C. Arc Lighting ...	...	1,600	...
Folkestone	Direct Three-Wire	...	460	210
Galway	Direct	...	130	110
Glasgow	Direct	...	500 & 600	250
Gloucester	Direct Three-Wire	...	250	...
Guildford	Direct	...	400	200
Halifax	Alternating ...	80	2,000	200
	Direct for Tramways and Power	...	...	...
Hammersmith	Alternating ...	50	2,200	110
Hampstead	Do.	90	2,000	100–105
	Series D.C. Arc Lighting ...	...	1,300	...
Hanley	Alternating ...	100	2,000	200 & 100
	Series D.C. Arc. Lighting ...	...	1,500	...
Harrogate	Alternating ...	50	2,000	200 & 100
Harrow	Direct Three-Wire	...	470	220
Hastings	Alternating ...	100	2,000	100 & 200
Hove	Direct Three-Wire	...	220	220
Huddersfield	Alternating ...	100	2,000	100 & 200
Hull	H.T. & L.T. Direct	...	2,250, 450 & 225	110 & 220
Islington	Alternating ...	50	2,000	100 & 200
Kelvinside	Direct	...	150	100
Kensington & Brompton	Alternating ...	...	2,000	100

Name of Station.	System.	Periods.	Generating Pressure.	Pressure at Lamps.
		∼	Volts.	Volts.
Kensington & Knightsbridge	Direct Three-Wire	...	110 & 220	100 & 200
Keswick	Alternating ...	75	2,000	...
Killarney	Do.	100	2.000	100
Kingston-on-Thames ...	Do.	77	2,100	105
	D.C. Arc Lighting	...	1,000	...
Lambeth	Alternating ...	...	...	...
Lancaster	Direct Three-Wire	...	240 & 120	200 & 100
Larne	Alternating ...	100	2,200	100
Leamington	Direct	...	113	...
Leeds	Alternating ...	83	2,000	100 & 200
Leicester...	Do.	50	2,000	100 & 200
Leith	Direct Three-Wire	...	460	230
Leyton	Do.	...	...	150
Lincoln	Do.	...	460	230
Liverpool	Direct	...	...	230
Llandudno	Direct Three-Wire	...	440	220
London (part)	Alternating ...	83	10,000	...
Londonderry	Continuous Arc Lighting ...	...	3,000	...
Manchester	Direct Multi-Wire	...	400	100, 200, 300 or 400
Metropolitan Co. ...	Alternating ...	...	...	200 & 100
	Direct Three-Wire	...	...	200 & 100
Middlesbrough	Direct	...	440	...
Monmouth	Alternating ...	60	3,000	120
Morecambe	Direct	...	1,400	220
Morley	Alternating ...	60	2,000	200
Nelson	Direct	...	120	112
Newcastle-on-Tyne (part)	Alternating ...	100	2,000	100
	Do.	80	1,000	100
Newington	Direct Three-Wire	...	450–500	220
Newmarket	Do.	...	420–460	210
Newport	Alternating ...	87·5	2,000	100
Northampton	Direct Three-Wire	...	220	105 & 210
Norwich	Do.	...	250	110 & 220
Nottingham	Do.	...	220	100 & 200
Notting Hill	Do.	...	200	100 & 200
Oldham	Direct	...	...	210
Oswestry	Direct	...	230	220
Oxford	Direct	...	1,000	100
Paisley	Alternating ...	50	2,000	200
Pembroke	Direct Three-Wire	...	250	...
Plymouth	Alternating ...	50	2,000	200 & 100
	Direct for Tramways	...	520	500
Pontypool	Direct	...	135	100
Poplar	Direct	...	450–570	...
Portsmouth	Alternating ...	50	2,000	100
Prescot	Do.	100	2,000	100
Preston	Direct Three-Wire	...	120 & 250	110 & 220
	Alternating ...	50	2,000	220

Name of Station.	System.	Periods.	Generating Pressure.	Pressure at Lamps.
		∿	Volts.	Volts.
Rathmines	Direct Three-Wire	...	250	...
Reading	Alternating ...	67	2,000	100 & 200
	Direct Three-Wire	...	400–450	100 & 200
Richmond	Do.	...	115–230	110 & 220
Rochdale	Do.	...	440–480	...
St. Helens	Alternating ...	60	2,000	100 & 200
	Direct Three-Wire	...	460	230
St. James', Westminster	Do.	...	...	107
St. Pancras	Do.	...	...	110 & 220
Salford	Do.	...	...	...
	Alternating ...	75	3,000	...
Salisbury	Direct Three-Wire	...	450	210
Scarborough	Alternating ...	80	2,000	100 & 200
Sheffield	Do.	100	2,050	100 & 200
Shoreditch	Direct	...	1,100	...
Shrewsbury	Direct Three-Wire	...	420	210
Southampton	Do.	...	230	100 & 200
	Alternating ...	50	2,200	100 & 200
Southport	Do.	50	2,100	100 & 200
South Shields	Do.	50	2,000	110 & 220
Stafford	Direct Three-Wire	...	108 & 216	105 & 210
Stockport	Do.	...	460	230
Sunderland	Do.	...	440	110 & 220
Swansea	Do.	...	440	...
Taunton	Alternating ...	...	2,000	100 & 200
Torquay	Do.	50	2,100	200
Tunbridge Wells ...	Do.	68	2,100	220
Ventnor	Direct Three-Wire	...	420–460	210
Wakefield	Alternating ...	60	2,000	200
Wallasey...	Do.	50	2,000	100
Walsall	Direct	...	2,000	105
Watford	Alternating ...	50	2,100	200
West Ham	Do.	50	2,000	100
Westminster	Direct Three-Wire	...	225	100 & 200
Whitehaven	Do.	...	210–240	100
Wimbledon	Alternating ...	50	2,200	
Winchester	Direct Three-Wire	...	420–460	210
Woking	Alternating ...	100	2,000	100
Wolverhampton ...	Direct	...	2,000 & 460	110, 220, & 440
Woolwich	Direct Three-Wire	...	420	...
Worcester	Alternating ...	100	2,200	100
Wycombe	Direct Three-Wire	...	420	210
Yarmouth	Alternating ...	83·5	2,000	100

Number of Direct-Current Three-Wire Stations = 73
„ „ Direct-Current High-Tension „ = 9
„ „ Alternating-Current „ = 62
„ „ Combined A.C. and D.C. „ = 16

Periodicities :—

∿ =	100,	93,	90,	87,	83,	80,	77,	75,	70,	67,	60,	50,	40
Number of Stations	20,	2,	2,	2,	7,	4,	1,	3,	1,	2,	8,	20,	3

Alternating-Current Generating Voltages :—

... but we ... one of ... in a ... with Mr. ... sugges- ... say that ... suggestive ... strengthened.

... advantages ... stage. ... England. ... [illegible] ... has ... been ... Mr. ... showing ... that ... lamp ... per cent. ... the same ... several years. ... much ... such ... will ... have ... of the ... that it ... that the ... I think ... behaved badly. ... alternating ... with regard to the ... the wide ... doubt that the ... manufacturers, ... alternating ... the alternating current. ... introduced into the ... way to be ...

There ... advantage of standardisation to the producer, but I think we must all agree with Mr. Sellon that in the end the advantage will come just as much to the user as to

the producer. We see it throughout all our ordinary purchases of life. In engineering matters perhaps the only thorough standardisations that have taken place have been in the small machinery which we purchase for domestic use, such, for example, as sewing machines. It is now time that the motors intended for use in houses should be classed with articles of domestic use; but it is only when they are standardised that they can be produced in very large quantities, and that we can hope to let the user have them at a price that he is prepared to pay. Quite recently developments have taken place in the use of electric motors which bid fair to increase their use very largely indeed; I refer to motors of $\frac{1}{3}$ H.P. and $\frac{1}{6}$ H.P., such as we should use in our houses either for small domestic power purposes, for ventilation, or for cooling rooms. It is in this direction that the trade has been stirred up, and of course that has induced standardisation as the first result, and the effect has been a very great lowering of the cost. The next direction in which we may hope for standardisation is the supply of motors for the working of tools which take a definite amount of power. There are a large number of tools used in workshops requiring a range of from $\frac{1}{4}$ H.P. to 1 H.P., and they can be grouped and motors be fitted directly to them. Apart from any special effort which this Institution may make, I think that by the operation of a natural economic law we shall, commencing with the smaller sizes, gradually standardise motors, and so from year to year get up to the largest sizes. But there is no doubt that this Institution can assist that law by calling to the attention of the user's engineer the enormous advantage that comes to the user by adopting the standards of the manufacturers themselves, and that is really the best way to get at the end we all desire. Mr. Crompton

Mr. A. B. BLACKBURN: I take it as a matter of course that we all agree with Mr. Sellon as to the desirability of standardisation, and the chief thing we have to consider is, to what limit we can go. Each manufacturer must begin to a great extent at home; he must standardise as far as he can, fixing his own types, and trying to convince the user that he has good reason for adopting them. By that means he may commence, as far as he himself is concerned, with a fair measure of standardisation, and then manufacturers will come to some understanding amongst themselves as to what are the best types. The user can assist them very greatly by pointing out from his experience the conditions to be fulfilled; and, if he will, as Mr. Sellon points out, state the ends, the manufacturers will find the means. As regards dynamos, the class of machinery in which I am chiefly interested, I think we have already arrived to a certain extent at a basis. For alternating currents there has been a great diversity of periodicity which has blocked the way to standardisation, but there is now a consensus of opinion leading to a definite periodicity, which, except in the case of stations already existing that must for a number of years be tied to their present periodicity, will very considerably lighten the task of the manufacturer. The same with regard to continuous currents; we are settling down very much. The table given at the end of the paper shows that a very large proportion of the stations are now using pressures between 400 and 500 volts, and that is bringing things to a very Mr. Blackburn.

Mr. Blackburn.

[illegible] the engine-makers will [illegible] different sizes [illegible] different engine-makers.

[illegible]

Mr. Slater Lewis.

[illegible] Speaking [illegible] manufacturers [illegible] per cent. The estab-[illegible] at the present moment are very [illegible] machinery that is [illegible] about by the fact that [illegible] full of all classes of [illegible] machines 15 [illegible] to do any good in [illegible] to standardise our [illegible] Unless we do that we shall go on in the old method of building all sizes and shapes of machines, in [illegible] and we shall be unable to work profitably and to meet foreign competition. My own view is, that if some Committee could be formed with a view to suggesting certain sizes of motors and dynamos, with uniform speeds, voltages and periodicities, we should arrive at something fairly satisfactory. I am inclined to think that Mr. Crompton is wrong in saying that these matters will right themselves automatically. I believe we are now standing face to face with a very serious problem, and the sooner we attack it the better, and that in a practical way. The firm with which I am associated has been engaged for some considerable time in standardising a series of dynamos and motors. They have already commenced operations with them, and I can only say that the results

have been eminently satisfactory, and that they hope in a short time to sell nothing but these standard machines, and under no circumstances to depart from that line of business. That is the only way to meet this foreign competition, but we must be supported by the consulting engineers. Those dynamo manufacturers who have to supply Corporation plant, and the like, to the specifications of consulting engineers, are suffering very seriously from the fact that all sorts of details are imposed upon them, involving not only much thought and experiment, but the alteration of patterns and drawings. We all know what a conglomeration of patterns, drawings and stores are to be found in almost every dynamo manufactory in this country, and until we can reduce them to a minimum we shall do no good. This is a matter which we dynamo manufacturers feel very strongly upon, and I for one should be only too pleased to see some definite steps taken with a view to standardising the dynamos and motors that we are called upon to supply, for, besides giving very good results to the manufacturer and to the user, it would be the most effectual way of meeting foreign competition. Mr. Slater Lewis.

Mr. E. H. JOHNSON: I have had much to do with standardising electrical apparatus in the past, but not in the direction indicated by Mr. Sellon's paper. My efforts have been to secure the standardisation of apparatus in its constructional details. Mr. Sellon has to-night, in my judgment, struck a keynote to which English manufacturers generally should give serious attention, as it affects the entire range of manufacturing interests, in the matter of foreign and particularly American competition. I should characterise Mr. Sellon's idea as "the standardisation of what is wanted," leaving to manufacturers the business of supplying that want in their own way rather than to employ engineers to draft and specify the details of construction. This individual specification of constructional detail is, in my opinion, the bane of your manufactures, and the prime cause of the difficulties of which you complain. It does not exist, at least to any great extent, in America. There a Tramway Company, say, calls for so many dynamos, to yield so many horse-power, and so many motors to propel so many cars. These the manufacturer can bid to supply of his own special form and type. The result is, the manufacturer having them in stock, so to speak, can supply quickly and at low cost. This, to my mind, is what is aimed at by Mr. Sellon, and will more effectively accomplish the improvement desired than would any other suggestion as yet made. Mr. Johnson.

Mr. J. S. RAWORTH: Mr. Sellon, like every practised writer of a paper, has thrown down upon the floor what I may term the bone of contention. Now it does not very much matter what the bone is, so that it be long enough for two dogs to get hold of it at the same time; Mr. Sellon has given us a very admirable paper which in itself provides plenty of scope for discussion, but he has also given us a title which does not fit. Therefore we can have as much discussion on the title as we can upon the paper—a discussion on two totally different subjects. Now in order to get you to appreciate this point about the title, I want you to consider the meaning of the word "plant," which is Mr. Raworth.

Mr. Raworth.

used in legal documents, and has a legal meaning, but concerning the meaning of which you never find in those documents a single word of explanation. Now what is plant? We sometimes hear of a person having two plants and three plants: but in fact he can only have one plant. Plant is the machinery, tools, and utensils used in carrying on any particular trade. When a charwoman goes past an ironmonger's shop, and sees buckets and scrubbing-brushes in the window, and goes in and buys them, and takes them away for the purpose of her business, they become plant immediately. But if a lady goes to a shop, and buys these buckets and scrubbing-brushes, they do not become plant, they become simply domestic utensils. So when you see plant spoken of in a specification it does not mean the engines and dynamos that the producer is producing and supplying to the consumer: it means all his tools and machinery that he uses in his business for the purpose of producing those things. That is always the meaning in every specification which you put your hand to. I have known town clerks and others try to make out that the clauses with reference to the plant, which are very onerous clauses sometimes, actually referred to the machinery that I was supplying to them under the contract. Now it seems very strange perhaps that you should not be allowed to speak of the stuff which is in the course of manufacture as plant. But I can only explain it to you in this way. I cannot get an analogy from mechanics; I must take one from the course of education. Suppose you go to a lady who is keeping a girls' school, and you ask her, "What do you turn out of this establishment?" She would say, "Demoiselles, young ladies, most accomplished and elegant." Then you would say, "But have not you any wives here?" She would reply in the negative. You see those young ladies will probably become wives, a great many of them, hereafter, but that is done by a legal process under the guidance of a parson. Now the machinery that Mr. Sellon turns out is not plant so long as he has possession of it, but when he gets the final certificate of the engineer, who acts as the parson in this case, the machinery becomes plant, under the control of the supplier of electricity; it is the plant of his business.

When we turn to the title of the paper, and read "The Standardisation of Electrical Engineering Plant," we mean the standardisation of the lathes, drilling machines, screw-drivers, and those things, which are part of the tools with which the electrical engineer conducts his business. Now the great advantage of this paper is that it gives us an opportunity of discussing both that and the other subject also.

Turning to the body of the paper, I sympathise most fully with Mr. Sellon in bringing this matter before us. I have done a great deal in it in the course of my life, with somewhat moderate success. I think that I should rather subdivide this paper under the head of standardisation of the *governing factors* as the first head, and the standardisation of *details* as the second. Mr. Sellon, I think, calls it in his classification
Sta-
attac ds, or performance. Now if you take the analogy of the railway
I am a call the gauge the principal governing factor, and it is because
standardis ers in the early days did not fully recognise the importance
commence they began by specifying gauges that were not all alike,

and consequently gave a very great deal of trouble, and caused the country an enormous sum of money to bring them into uniformity. Now the analogous questions in electrics to gauge in a railway are, I take it, periodicity and pressure principally. And when you look at Mr. Sellon's list at the end of the paper, you will find that some considerable effort *has* been made to get at standardisation. You will find that there are twenty stations which have a periodicity of 100. I think that you have to thank Mr. Mordey and myself for that to a great extent. I do not know whether we were right or not. I think the probability is that we were wrong, but however we did attempt standardisation, and without the assistance of any consulting engineers we managed to account for most of those twenty stations which were standardised at a period of 100. It has been proved later that a periodicity of fifty would give better results, and now we find that no less than twenty stations in a very much shorter period of time have been standardised to a periodicity of fifty. That is a solidly satisfactory result, and I think it shows that the consulting engineer is after all coming very much nearer Mr. Sellon's standard than he imagined. Of course we cannot do very much to help the matter on, we have to take what the consulting engineer gives us. Mr. Raworth

I quite agree with Mr. Slater Lewis and Mr. Crompton that the standardisation of detail has a very much stronger effect upon the cost of production than most people are aware of, a far stronger effect I think than the standardisation of the pressure and periodicity. But how is that to be got? I have been connected with a Company that has done much in the way of effort at standardisation, it has passed resolutions, it has given instructions to managers, it has written innumerable memoranda, in fact it has exerted itself to an enormous extent to get standardisation; but you do not get it. The ordinary commercial draughtsman can upset all the calculations of Board or Manager by the simple expedient of altering things as he goes along, without anybody finding it out. I came across a peculiar instance the other day. I wanted a new valve-spindle for an engine, and I ordered it from the engineer who made the engine, only about two years ago. When it came I found the standard had been altered. But how much do you think it had been altered? It had not proved too weak, and been made stronger, but he had altered it by making it $\frac{1}{32}$ of an inch smaller. Now what good in the world was achieved by making the spindle that much smaller? It did not fit: the engine had to be taken down twice to get it put in, and a new one had to be made, to the great expense both of the original manufacturer and of the user. I think that Mr. Sellon would be well advised if he were to carry out the suggestion, because I believe it is the only satisfactory solution of this question, that anybody who wants to standardise satisfactorily after the manner that Messrs. Willans & Robinson do, but without taking all the time that they have taken to do it, must keep upon their works a cauldron of boiling oil in readiness for the man who alters standards.

Mr. Mark Robinson: If I add a few words to what Mr. Sellon has said so well, it is only because I have given a good many years, and I think not wholly without success, to the problem of standardisation in

Mr. Robinson.

one branch of manufacture. Mr. Raworth has said something about the long time my company took to achieve it, but without going into personal matters it may perhaps be of interest to say that when, eighteen or nineteen years ago, certain works which he has in view were started for making engines for small steam-launches, it was determined to standardise them. When the first order for a 4 h.p. engine was received, half a dozen such were put in hand, in the faith that the other five would find buyers. They did. Standardising was started with the very first piece of work done in those shops, and that principle has never been departed from. Having had that amount of connection with the subject, it is perhaps well that I should offer a few words of encouragement in aid of Mr. Sellon's object—since, as Mr. Crompton well said, there is really nothing to be said about his paper in the way of criticism. We all agree about it, but by way of helping on Mr. Sellon's object, I would say that in the works in question the standardisation is certainly not less than in any American shop, and it is carried out not less perfectly, while its course has never been interfered with by opposition either from consulting engineers or from anybody else. I do not think the consulting engineer is so black as he is painted; he specifies a low speed for his engines sometimes in his electrical specifications, meaning that he will have nothing to do with high-speed engines, but he makes his meaning clear, and when he leaves it open for high-speed engines he rarely inserts any clauses which give trouble. I take it this is due to the fact that the people who make such things really know their own minds, and have convinced the consulting engineer that they have some knowledge and some experience behind them. When this is proved to him the English, like the American consulting engineer, is only too glad to avail himself of the manufacturer's experience. That is how the matter appears to me, and I believe that if our electrical friends would attack the problem with the same determination and the same courage, it would very soon eventuate as they wish. Mr. Sellon says that standardisation presupposes a sufficiently enduring demand. As I started with the hope of saying a few words of encouragement, perhaps I may be forgiven another retrospect which is largely personal. More than two years ago there was an engine of 1,200 h.p. ordered in the works in question, and it was a very great advance on anything that had been done before. In pursuance of the practice of the firm, a much larger sum than the price of that engine was at once spent upon standard jigs and templates, and so on, in the full faith that it would come back again. It was perhaps a question whether 1,200 h.p. was not too big for the type, but we believed it was not, and before the first 1,200 h.p. engine was ready to go out of the place I think there were eighteen or twenty on order. The jigs and templates, which insured that the very first should be perfectly interchangeable with all its successors, were of course abundantly paid for over and over again. Mr. Blackburn, referring to engine speeds, said that engine builders might help the makers if they would standardise their speeds. All I have to say is, that if dynamo makers will express a wish as to any standard speeds, I have no doubt the engine makers will rise to it directly. Mr. Raworth remarked upon

the ease with which efforts at standardisation could be neutralised by the carelessness of a draughtsman, and he instanced a case. I do not think there is any real difficulty in so organising the duties of draughtsmen and other people as to make it certain that changes shall not be made except under proper sanction, and that when they are made, for the honour of the makers, duplicates shall be kept in store of everything, however obsolete. If it were sent out years previously, it should still be kept there for the benefit of the users. This paper is a very valuable one, for it calls our attention to a matter of burning interest to the trade of the whole country. Mr. Robinson.

Mr. R. Hammond: The most interesting sentence which I find in Mr. Sellon's paper is at the bottom of p. 294, which runs: "Assuming, then, that the buyer's engineer has come to stay, it would appear that a condition precedent to the standardisation of plant is the standardisation of the buyer's engineer." I belong to the class of gentlemen who, according to Mr. Sellon, has to be standardised, and, as one manufacturer has succeeded another, I have felt the process of standardisation going on. Some seem to think that this question is one that only concerns producers. Now, I am heartily with the reader of the paper in saying that it concerns the industry at large. That seems quite obvious, but it is not always generally held. The most important thing for the buyer is to get the best plant, and next to that is to get it as economically as possible. The proper spending of capital in an industry is manifestly the one great feature round which the success of the industry will turn, and nothing will help the proper spending of capital so much as the standardisation of plant. Of course, as Mr. Raworth says, in the early days we all had our ideas about periodicity. He and some of his friends were responsible for the 100, and I think possibly I was responsible for these curious figures in the table which appear as a periodicity of 83, 84·5, 87, 80, 81, and 82. But I would like to explain that all those plants really came off one standard, with complete alternations of 10,000 per minute; but when you give this plant to engineers in stations, they find it convenient to run a little faster or a little slower, and so in making up these returns, instead of returning them all as a periodicity of 83, they have returned them at the various periodicities quoted. We have arrived at a time, I think, when consulting engineers, who are not so black as they are painted, do feel that their greatest trust is to see that buyers have their capital spent economically. We have heard from the manufacturers to-night, and I think it was Mr. Raworth who introduced the homely illustration of the children at school. I would say of the manufacturers that it is natural they should consider their children, their own particular children, as prize babies, and the best babies ever born. One little disadvantage that the manufacturer is under is that he sees so much of his own baby, and therefore he perhaps unduly prizes it. The one advantage of the consulting engineer is that he sees the babies of many, and he is able to compare them, and is able finally to decide upon what a model baby ought to be. Mr. Hammond.

Mr. Sellon has made one admirably good suggestion, and that is: Back up your Institution, and back up its Uniformity Committee. That

Mr. Hammond. Committee has perpetrated one act: it has said that there should be a periodicity of 50 for lighting and the distribution of power on a small scale, of 25 in the power transmission schemes, and of 100 for converters in people's houses. The alternating system was first used for converters in people's houses on the premises, but we found soon that we had to group the converters, and it only shows how difficult it is, even for a Committee of this Institution, to get things perfect, because with regard to the recommendation of beginning with 100, I cannot help feeling that they made a little slip. Mr. Sellon's suggestion that the Council of the Institution and this particular Committee should be assisted by specimen manufacturers, standardised ones, who have passed through the callipers of the Plant Association, would do good. Bring not only the manufacturers but the users and the users' engineers, and then the buyer will get more economically what he wants to get. With Mr. Raworth at one end, I am the dog at the other end of the bone, and while he is giving his definition of "plant," and that which he endeavours to explain to town clerks, I am glad that I have not been the dog at the other end of the bone who has been trying to get away the bone from him for the town clerk. There is one thing, at all events, that I have found it necessary to standardise at the very beginning of my specifications, and that is to state that the word "plant" shall mean all the materials and all works to be supplied by the contractors, and therefore, if I had been at the other end of the bone, that town clerk would have found the words set forth. Let those who are consulting engineers take home this lesson at all events to-night, that it is our duty not to aim at brilliancy, but to be content with the humbler task of seeing that the manufacturer gives what he has contracted to give.

Mr. Ferranti. Mr. S. Z. de Ferranti: I have listened to this paper with exceptional interest. It is a paper which contains matter of vital importance not only to the electrical engineering, but to all the engineering, industry of the country. The paper is full of sound common sense, and much to the point, and is so valuable in all the remarks which it makes and the definitions which it lays down, that I am only sorry it was not read ten or more years ago, because a great deal of the evil of non-standardisation has already been perpetrated, and that evil is here unfortunately to stay in most cases. Look at all our alternating stations in this country, and you will see at once what I mean. There are quantities of periodicities, and if you multiply those periodicities by the speeds which it is necessary to run at to serve different people's ideas, and then multiply again by the different sizes of plant that it is necessary to supply, you will find that the number of different alternators is simply colossal. In fact, it is hard to find many machines of any one type alike, and that is why I say that the evil has already been perpetrated, and is unfortunately here to stay. It is very difficult, once a periodicity has been fixed, to make any alteration. In one solitary case I have arranged for a 40-periodicity station to be raised to 50 periods so as to get that good standard, but that is only one case in my experience throughout the country. In one case some time ago, when supplying machines, I begged the engineer of a certain station to change from

100 periods to 50, because, as I told him, I felt satisfied that it was the thing to do, and would pay well for the doing. He felt that, in adding a 500 H.P. plant, the change was more than he could possibly allow, taking into consideration what a large proportion that was of their output, and yet now that 500 H.P. plant is the only one of that time remaining in the station. All the others for which the periodicity was kept have disappeared, and now that large station is thinking of going in for continuous-current distribution, fed by multiphase from outside. I feel sure that course would not need to have been considered had the change in periodicity been made at the time indicated, or, in other words, had a known standard existed at an earlier period. In America I believe they started with 120 periods, and they kept to it, so that all the plant was made to the standard. A few years later on it was found that that was far too high a periodicity for which to build machines satisfactorily, because it is largely a question of mechanical design. The periodicity was then halved, so that there they have for ordinary alternating work for lighting supply a general standard periodicity of 60 periods. I have heard a very curious thing stated—I forget where it came from—that the standardisation of voltage was not in all cases the best thing. I heard some one remarking upon a certain supply having a voltage of 105 instead of 100 or 110, both of which had previously been looked upon as standard voltages, and the explanation given was that it enabled the station to use what were practically the spoiled lamps from the other two voltages. Now the argument was certainly a practical one, and it seemed to fit in perfectly well, but it was an argument of selfishness, and that selfishness, I think, is largely at the bottom of all our trouble in want of standardisation. It has often been said to me when I have tried to get a standard periodicity fixed upon, "What difference does it make to me? How shall I be any better off if I change to that standard? I am a buyer; why should I not keep what I have already? Why should I not have what I think will do?" Of course it is a very shortsighted argument, and simply shows that whoever uses it does not appreciate the reduction in cost which follows upon standardisation and repetition of manufacture. Mr. Ferranti.

I agree very thoroughly with Mr. Sellon's views on what the consulting engineer should do, and if I may say so, without desiring to be in the least harsh or unpleasant, I should like to suggest very respectfully to this Institution that the true function of the consulting engineer is fully to appreciate the scheme that he is carrying out, and, having appreciated that scheme, clearly to lay down the ends which he desires to accomplish, and to leave to manufacturers and people tendering the means which they think fit in best with his standards, and which they think best meet the conditions which that engineer desires to accomplish. Then his great work comes in in sitting in judgment on behalf of his client upon the various offers made under his requirements, and telling his clients not which is the cheapest, not which is right in this detail or that, but telling his clients what it will pay them best to buy.

General WEBBER: I propose that we should adjourn the discussion. General Webber.

General Webber.

There is a great deal more to be said on the subject, and I think the debate this evening will lead others to speak and supply us with statistics and figures which, although not wanting to Mr. Sellon's paper, would very much add to its interest.

The PRESIDENT: I have to announce that the scrutineers report the following candidates to have been duly elected :—

Members:

William James Binnie.
Alfred Colson.
John Pullar Phibbs.

Associate Members:

Alfred Leslie Cook.
Frank Arnold Greene.
John Wyatt Papworth.
Henry Wilder Warde.
Hal Williams.

Associates:

Rooke Ainsworth.
Harold Helfrich Bicker-Caarten.
Charles Edward Stewart Bill.
Richard Hodgson Black.
Joseph Dickson.
Alexander Philip Dryburgh.
George Flett.
William Henderson.
Gerald Arthur Hill Hill.
Thomas Holbrook.
Otis Carter Formby King.
Robert Gardner Masaroon.
Hugh William Pinkerton.
Richard Francis Read.
S. Rosenbaum.
Harry Randal Rylands.
Sidney Arthur Simon.
Frederick William Stamp.
James Thomas Webster.
Frank Henry Whysall.
Ernest T. Williams.

Students:

Fitzroy Tozer Chapman.
Alfred Singlehurst Cross.
Thomas Clemenson Evans.
Cyril Renton Heron.
Theodore Arthur Hill.
Walter John Line.
Walter McBretney.
Robert William Milsted.
Albert Henry Midgley.
John Palmer.
Edgar Phillips Perkins.
John Ernest Schofield.

The Three Hundred and Forty-Second Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 22nd, 1900—Professor SILVANUS P. THOMPSON, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on February 8th, 1900, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Gray, Harold.	Rolph, William Mair.
Hoadley, Edward Ernest.	Sully, Herbert Thomas.
Nimmo, William Henry.	Vaughan, John Crake.

Weymouth, George Andrews Philip.

From the class of Students to that of Associates—

Hounsfield, Francis Cecil.

Donations to the Library were announced as having been received since the last meeting from Professor A. E. Salazar and the Electrician Printing and Publishing Company, to whom the thanks of the meeting were duly accorded.

Mr. F. Ayton and Mr. J. Papworth were appointed scrutineers of the ballot.

The PRESIDENT : Our next business is the resumed discussion upon the paper of Mr. Percy Sellon on "The Standardisation of Electrical Engineering Plant," and I will call upon General Webber to resume the debate.

General WEBBER : The subject before us is admittedly a dry one, although some matters which were amusing were introduced into the discussion at our last meeting. To the amusing part I do not think I can add, because it seems to me that the subject is one which requires General Webber.

General Webber.

very grave consideration. I would like to draw attention to its action on the Continent of North America, where the standardising of plant has been brought about by the circumstances of the demand. For the smaller kinds of machinery, the standardising of each individual manufacturer holds the ground, such as for the smaller sizes of dynamos and motors; but for all large units of plant and for complete combinations of these units with the plant used for traction purposes, the trade has settled down into an exceptional condition. For instance, in utilising large water powers, the units of the generating plant are naturally very large, and the engineer, when devising a scheme for using these, naturally turns to the maker who can provide units the size of which is only limited by previous experience of what is possible. Similarly, in connection with traction, the manufacturers able to meet the demand have had it all their own way, and their standards have necessarily to be adopted by the undertakers. In America, these industries have fallen into the hands of two or three great manufacturing firms, partly because of the large amount of capital at their disposal, and partly because they have bought up or inherited the tail end of master patents which had been established before the Courts and which protected them from infringements during the days when the market was beginning to expand, notably the Westinghouse and the General Electric Companies, both of America. Once such combinations as these command the market for particular kinds and sizes of plant, with their accessories, competition disappears, and their charges are only kept in check by the public opinion within the industry. Their position is quite different from that of the numerous makers of smaller articles and specialities who employ, say, three or four hundred workmen, and of whom there are examples in nearly every great city of the United States. In the former case, the heavy general charges are covered by the vastness of the output; in the latter case, these charges can, by the personal attentions of the manufacturer, be kept down to a much smaller percentage.

As with us at home, these manufactures of the small and special articles, which are in great variety and which are subject to the idiosyncrasies of makers and inventors, differ in pattern and quality in various works. It is not easy to see how standardising can be approximated to under these circumstances, except, indeed, when, as in the case of the glow-lamp and telephone manufactories, the patents have created and guarded monopolies of manufacture. It will be thus understood that standardising in the case of the larger units ensures no economy to the user. The capitalist who has provided the money by which standardisation is possible does not do it for the user's benefit. This is especially true in the case of electric machinery, because, unlike, for instance, sewing-machines or clocks, electric plant has to be used in combination with other engineering plant, and an engineer has to be employed to instal it so that it can be used, and he casts about amongst the standard stocks of the various manufacturers until he finds something suited to his wants; although his choice is affected by price, he naturally, for his own reputation's sake, specifies both quality of manufacture,

General Webber.

endurance, and accessories, so that his client may have an article which will be both efficient and durable. Herein lies the advantage of many manufacturers with many standards. The ability of the engineer, with such a variety of choice, shows itself in the knowledge of, and experience with, these numerous standards, and not in his cleverness in framing an ideal specification which fits into none of these standards.

The matter, however, becomes very serious when the export trade is considered, although I have great faith in the eventual conquest of the market, even in the remotest places, by good and efficient machinery, particularly of the class which generates and utilises electrical energy; because, unlike machinery which is subject to intermittent use, it is of a kind which, owing to its continuous running, requires endurance, and, therefore, the best quality of workmanship.

It may be said that the way in which the great American manufacturers are able to meet sudden external demands is a counterpart of the condition of the trade in agricultural implements, which, not many years ago, was secured and held by the English makers.

Those who admire large manufacturing monopolies, from which the public has to accept in a lamblike way the standards they adopt, are generally those who benefit by them. They speak of having eliminated the consulting engineer from these industries in a triumphant way. They themselves are men who, if they had been originally educated as electrical engineers and had gone through the curriculum which is now considered desirable, would have themselves been forced into the competition that must exist in the profession. In fact, they would have probably been strictly professional men; but their opening for occupation has been more in the direction of being agents for the monopolists; in fact, a sort of bagman with some scientific and engineering smattering, and I look upon this as the outcome of a distinctly unhealthy absence of the competition which non-standardisation produces.

The natural object of each maker is to standardise his own plant. In the early days of the industry in this country we find many examples. The makers held the patents, they had gone to great expense in protecting these, and in establishing plant and machinery for manufacturing on a large scale. If one takes the published descriptive catalogues and price lists of, say, half a dozen well-known makers in 1890, for instance, and compares them, it is very curious to find that in speed, output, and price there is small resemblance. The conditions which have governed the combination have, one would say, been governed by accident, although it is certain accident had nothing to do with it. I think one is bound to believe that each type was one which the maker honestly believed would successfully compete with those of other makers which it would approximately resemble. Dynamos, as they were called, could be procured with a reputed maximum output of 990, 1,000, 1,500, 2,200, 3,000, 3,250, 4,000, 4,095 watts, and so on for 40 or 50 sizes. The purchaser, if he obtained half a dozen lists, was bewildered over the varieties of conditions offered. In this way, for want of a combination for standardising, an immense amount of capital was wasted. The wants of the users of small-sized

General Webber.

dynamos may have been met by this plethora of types, but it answered no really practical purpose. A customer's engineer no doubt found it very convenient to have a selection amongst the continuous-current machines of various makers which fulfilled such conditions as the following. For instance, with 1,200 revolutions yielding 4,900 watts the price was £60, and so on with various types and various prices, with 1,200 revolutions as the reputed speed of the machine. It may be remarked that it naturally led to a variety of discounts, and all sorts of conditions intervened to help the consulting engineer to a choice, which rarely could be governed by the absolute merits of the machine. The Brush Company was at one time very near securing the command of the market with their arc-lighting dynamos. Their 60-light series-dynamo was in its way an unique machine, and if the field of public lighting in these kingdoms had not been occupied by gas, the Brush system, I have little doubt, would have gained a strong and permanent footing, which would have led to a kind of standardisation of arc-lighting plant. A 60-light machine costing £600 worked 60 lights in series, costing 1d. an hour per light, with great accuracy and efficiency. I do not know what the manufacturers would say to the work of a committee under this Institution of Consulting Engineers, who would carefully investigate the whole subject. I cannot help thinking that we have looked to Government departments as the means by which standardisation could be brought about. But it is a very curious thing that except in departments like the Navy, standardisation is very little assisted. For instance, take the case that is now so prominently before the public as regards the question of the supply of warlike material. Think, for instance, of projectors, numbers of which may be wanted in the field in South Africa. Those for coast defence are not well adapted for the field, not being mobile, therefore there is no reserve suitable for this application of the use of a projector. Mr. Crompton would tell you—I do not know whether he is here to-night—that when he went down to Chatham, where all inventions of this kind are brought before a special committee for consideration as to their merits, and where also, if anywhere, stores of such articles would be kept and where a standard projector would be on view, he found a series of machines which had been bought from time to time for the purpose of consideration and examination by the committee whose business it is to test them for warlike purposes. In this way, the funds which are supplied in very limited amounts by public departments, have to be spent, because even if they were hastily to standardise a projector for warlike purposes, it would in two or three years be out of date in many of its details.

Mr. Sellon has not laid before us the copy of a standard specification which he thinks would result in securing "the ends" and "performance" that is most desirable both in the interests of the market and the user. I wish he would examine with this view the old Admiralty specifications which were issued in the eighties for manufacturers of electrical plant to tender. If I recollect rightly, the best of these specifications [illegible]emely well drawn up. As regards the objects

that Mr. Sellon has in view, after all, a user like the Admiralty must know best what it wants, and is not likely to be ruled into a restricted form of specification, which means high prices, by what are sometimes called the "fads" of consulting engineers. I quite agree with him that everything that leads to a determination of standards by the organised efforts of the industry is wholesome, and I think that the Institution should be very grateful to him for his paper as a means of bringing the subject under discussion, and I hope that a practical result will be that many of our members will turn their attention to what is possible in the direction which he indicates and will not, after this paper has been read and discussed, give up the consideration of the question, but from time to time will urge on the Council the appointment of committees, like the "Wiring Rules Committee," to consider questions of standardisation in which the Institution ought to engage, both on behalf of the profession and of the industry. General Webber.

Mr. W. B. Esson: If we are to have cheapness of production and give our customer the best value for his money we must have standardisation carried much farther than it is at present. But the more the subject of standardisation is considered, the greater appear the difficulties in the way. Although we may all know exactly what we want, there is very considerable diversity of opinion as to the precise manner in which that result is to be obtained. Mr. Sellon's paper has dealt with two distinct kinds of standardisation, but he has not drawn a very clear line between the two. The first is standardisation between the manufactures of *different* firms; the other is standardisation in the manufactures of *particular* firms. As regards the first, we have in America and on the Continent apparently no greater agreement than we have in this country, because no two manufacturers have lines of machines which give the same outputs, speeds, and so on, and every firm is its own authority as regards frequency. The other kind of standardisation (inside the works, if I might so put it) is, no doubt, carried on to a much greater extent in America than in England. I am not sure, however, that there is much fixity of design yet, because in the American machines that I have had the opportunity of examining there appears to be a continual difference of pattern. They are always improving them, just as we are here, but the American manufacturers are fortunate in having such a great demand that they are able to construct a great number of machines in each batch before they alter the pattern. I quite agree with the statement of Mr. Slater Lewis that if electrical engineers in this country, instead of endeavouring to run the whole gamut of electrical apparatus, would confine themselves to the production of one particular thing, great economies would be manifested. But the fact is that no one firm in this country has enough of any one class of machines to keep them going. There are now, perhaps, six large firms constructing alternating-current apparatus. These firms also make direct-current apparatus, and the consequence is, of course, that both are constructing more expensively than if half the firms confined themselves to one class of apparatus and half to the other. If Mr. Slater Lewis contemplates combination amongst the larger firms I am quite with him, but I wish to point out that it is only under such Mr. Esson.

Mr. [illegible]. conditions as would guarantee certain machines going to certain firms —all the continuous-current dynamos going, perhaps, to one firm, all the alternators to another, transformers to a third, arc lamps to a fourth, and so on—that his proposition could be carried out, and I believe that there will come one day in this country, something in the way of a combination which will be a very great step towards standardisation.

Every firm has already its lines of belt-driven dynamos, motors, etc., and I have never known a consulting engineer who would not accept a good thing out of stock rather than invent a specification for it. To be sure, absurd things are occasionally specified by consulting engineers, but if you expostulate they generally tell you that the reason for it is that they have been bitten by some contractor and that they are obliged to be on the safe side. I do not think also that consulting engineers are unreasonable if you put the case fairly before them. Again, they are a sort of living compendium of all the mistakes made by contractors, and if you happen to be going in a wrong line they will probably put you right and say that so and so, on such an occasion, did something similar which proved disastrous, and that you had better steer clear of that. There are very great difficulties in specifying ends without to some extent defining the means by which they are to be attained, because, in providing the means, you thereby get the guarantee required as to the fulfilment of the ends for a long period. Take for example the insulation of a machine to run at 440 volts. The engineer will say that the means by which this running is to be obtained is that the insulation shall be such as to stand an alternating pressure, say, of 1,000 volts for an hour or half an hour, as the case may be. In that he has a guarantee that the machine will go on running for a very long period without breaking down. I have known a specification— though I do not think it was ever enforced—where a machine of 440 volts was specified with an insulation to stand an alternating pressure of 5,000 volts for an hour. This was, of course, beyond all reason, but the explanation was that the buyers thought they would be on the safe side.

I take it that Mr. Sellon desires to call attention not so much to the standardisation of small isolated plants as to that of medium-sized plants for central lighting and traction stations. There is very great difficulty in this because of the different lines of engines made. Some engineers prefer a three-crank, others a two-crank engine, some have triple expansion and some compound, some high-speed and some low-speed, and the consequence is that it is very little use trying to standardise such things as steam pressure and pressure of supply and pressure of generation, until you get some sort of uniformity amongst the engine makers. Of course if you make both dynamos and engines it is a different matter, but in this country the dynamo makers generally have to purchase their engines, and the engine makers their dynamos; and it is much less expensive to adapt a dynamo to suit an engine than *vice versâ*, because engine patterns are very expensive and alterations to engine patterns are very costly as compared with alterations to dynamo patterns.

We are beginning at the wrong end, and beginning badly, by fixing a hard and fast line, for instance, for the frequency. By doing so we necessitate the altering of patterns for every size and speed of engine, and if the object is to standardise manufactures, we are doing the thing best adapted to make that an impossibility by fixing frequency. In America the driving of large alternators by belts or ropes is very much more prevalent than with us, and a uniform frequency only means in this case a difference of pulley. In Switzerland, turbines are constructed to suit the machines, and it is a matter of fact that turbines are altered with very little expense, and the uniformity of frequency therefore imposes no difficulty. But with us it is quite different, and under present conditions the fixing of the frequency at one particular value would impose very great trouble on the manufacturer. The Uniformity Committee have endeavoured to do this very thing, but I doubt if they have realised exactly what it means. Within wide limits the frequency really is of no importance; between 40 and 60 one frequency is as good as another, but many do not realise this. In my practice I have gone to a frequency as low as 22, but the circumstances were exceptional. In ordinary cases anything between 40 and 60 is satisfactory; the choice depends on the patterns in stock. It is significant that the firms on the Continent who carry out large power contracts have no fixed frequency, the consequence being that alterations to patterns are reduced to a minimum. The patterns, stampings, etc., for 100-kilowatt machines come in for 120 kilowatts, when driven faster with an increased frequency, no alteration being required to the carcase. According to the Uniformity Committee the frequency ought not to be altered, but the construction of the whole machine ought to be altered in consequence. Presumably when it realises what this means, the final recommendations of the Committee will be revised. This matter requires to be better understood. The other day a consulting engineer wrote us asking what it would cost to re-wind 1,000 kilowatts of transformers we had supplied for a frequency of 83, as now it was proposed to transmit the supply from a distance at 50 frequency. Of course we told him that the transformers required no alteration whatever. If the buyers' engineers realised that a transformer that works at 40 would work equally well at 60, and *vice versâ*, with the same heating, and no appreciable difference in efficiency, they might be inclined to allow contractors more latitude. So far as I know, consulting engineers have never dogmatised about frequency. It is only the manufacturers who have done this, and the officials of Mr. Sellon's company worst of all. The consulting engineer, seeing an utter want of uniformity among the manufacturers, and knowing that the mean frequency for new installations is about 50 nowadays, specifies accordingly, and really it is very difficult to know what else he could do; but I am sure he does not care what the frequency is, provided it is within such limits as do not interfere with the efficiency of the apparatus. I have no doubt that on the matter being presented fairly he would accept any frequency between those limits, provided the conditions of the supply allowed him.

Mr. Esson.

Mr. Esson. Mr. Raworth has compared the differences in frequencies to differences of railway gauge, but surely there was never such a misleading analogy. Uniformity of railway gauge is of paramount importance because of the through traffic. Through trains run from London to Aberdeen over the lines of no less than four companies in succession daily, but we have nothing analogous yet in electrical distribution. There is no occasional call, say, from Edinburgh for a supply of electricity from Newcastle, and the working of these two cities at a different frequency is absolutely unimportant. With regard to motors, it is very easy to modify the windings for different frequencies, and the matter is scarcely worth considering any more than is the winding of the shunt coils on arc lamps. These are not the things that are costly, but the alterations of patterns to keep the frequency uniform. In conclusion I would say, let us be very careful that we standardise the right things. Frequency is not one of them if cheapness and facility of production are the *desiderata*. Fixing the frequency hard and fast only defeats the object in view. Rather let the manufacturer be given as large a selection of frequencies as circumstances will permit, and be allowed to choose within limits the one that suits his patterns best. Otherwise, to use Mr. Raworth's homely analogy, we may be dropping the bone in the attempt to catch the reflection. We want a real reformation, having something practical for its basis, not something which has only an academical value, as I think frequency has.

Mr. Evershed. Mr. S. EVERSHED: I suppose we have most of us had the experience of reading a book at some time or another and findly how aptly the author sets out a number of our own favourite ideas; in fact occasionally the pleasure rises to such a height that one feels quite drawn towards the author. When I read this paper my pleasure was very much of that sort. I felt that these ideas that Mr. Sellon puts forward so very clearly had long been dormant within me, and when I came to the phrase with regard to the standardisation of the buyers' engineer, I could not resist a spontaneous tribute to the style and the matter of the paper. I am not quite sure, however, whether I agree with it altogether. That standardisation is very desirable, and a pressing necessity in England, most manufacturers are agreed. How it is to be arrived at is another matter. Mr. Sellon's point with regard to the buyers' engineer is that his standardisation is a necessary preliminary, but I think in attempting to standardise the consulting engineer Mr. Sellon and those who agree with him are entering on a task which is much more formidable than they imagine. Mr. Sellon rather treats the buyers' engineer as though his tendency to unnecessary restrictions and undue interference were an isolated fact; as though the disability we are all conscious of labouring under were entirely confined to electrical engineering. Now it is not so; it is only one of the many instances of the temperament which is growing in Great Britain. Formerly our rulers were quite content to let new industries struggle to their feet just as they could without any interference, but in these days no new industry can possibly start without many restrictions, rules, and regulations; Parliament pouncing upon and attempting to regulate it in every possible and many impossible ways. We know for how many years

the electric lighting industry was made impossible by the fussy busybodies who invent the kind of legislation so prevalent just now. It is not only in our own profession that this interference takes place; it is widespread throughout the whole of the country, and is increasing rapidly. Mr. Evershed.

The moment you put any ordinary Englishman in a position of authority he becomes a changed man. If you take one of our own members, for example, and put him in a position of authority, either as consulting engineer or in any other capacity, he feels obliged to draw up a little private Act of Parliament of his own. Until Mr. Sellon can show us some way of altering the temperament of the average Englishman, I am afraid we shall have to put up with the unstandardised consulting engineer. But I am not at all sure we cannot do some good in spite of him, and when we manufacturers have begun to do good the consulting engineer will very likely help us. In my opinion the right word fell from Mr. Blackburn at the last meeting when he said that something could be done by beginning at home, by manufacturers standardising their own plant. It is true that what Mr. Esson has just said is rather disheartening. He takes the view that we cannot do anything very much, but I think some kind of combination among manufacturers, not to settle types or details of machines, but what should be the sizes and outputs of machines, what should be the definite sizes for cables and so on, might go a long way towards cheapening production, because every manufacturer would know what sizes he was to make. Mr. Robinson rather capped the remarks of Mr. Blackburn, but I think we most of us to some extent discounted what he told us because he always speaks to us with cheerful optimism, and we know very well that the difficulties his firm may have met with in standardising were certainly very much less than they would have been if the Willans engine had not been a perfect machine, which commanded the market from the very moment it was placed upon it.

Now I in my humble way have been attempting to standardise certain branches of electrical manufacture, viz., instruments, and I must confess that my experiences so far have been simply disheartening. The consulting engineer very rarely specifies impossible dynamos, but when he comes to instruments he appears to think that anything is possible. One eminent consulting engineer specified for some device to be added to an instrument to show which way the current was going, but he said that device must not contain a permanent magnet. I told the people who sent me the inquiry that I thought the engineer must have made the greatest discovery since Faraday's time. I went to see him, and he told me that he had made no discovery. "In fact," he said, "I am tòld that what I have specified is impossible." "Yes," I said, "it is." "Ah, well, I should not insist upon that." The instrument maker is constantly asked to design impossible instruments to put upon boards. No doubt each instrument maker gets out a design, but only one gets the order. But they all have to be paid for the designs which they have made. Ultimately the consumer has to pay for them. One consulting engineer specified for an instrument with

Mr. Everdhed.

a scale 10 inches long and capable of being read to 2 per cent. at any part of the scale from zero to the end. I pointed out to him that each division would then measure something like the 50th part of an inch, and he had to confess that he could not read it, but stated then that he meant it should be read to that accuracy on the centre or useful part of the scale. They not only specify impossible conditions with regard to accuracy and so on—and when the right time comes I shall certainly have some suggestions to make with regard to accuracy, because in those respects specifications can be standardised—but they specify as to how the instrument maker shall make his instrument. They never tell the dynamo manufacturer that he has to make his dynamo so that it can be bolted to the ceiling, but they have not the least objection to specifying that the instrument, for instance, shall stand on its terminals—about the worst way of fixing an instrument that you can possibly imagine. Yet we have had many inquiries, and we have had actually to supply instruments which are so placed. I do it, but only under protest. The designing of an instrument so as to reduce the strains and stresses to a minimum takes very considerable time and attention, and in designing it one naturally has in view what part of the case of the instrument is going to be used as the bedplate for bolting it to the switchboard. But the consulting engineer settles how it is to be bolted up—it does not matter what the inside is like; it is to be bolted up on its terminals, and there it goes. Again take the case of edgewise instruments which every instrument maker now makes. One engineer said, he did not want to put them up edgewise, they should be put up with their scales horizontal; nor did he want our fixing for holding them down to the switchboard, because he was going to make a hole through the switchboard, and put the instrument through from the back. Yet the very object of the edgewise system is that the instruments shall occupy a small transverse space; if that is not wanted why should that type be used? In all these ways the consulting engineer is at the present time keeping the prices of instruments up to an abnormal level. The cost of alterations to an instrument bear a far larger proportion to its total cost than in the case of the dynamo. It may cost, in an instrument which will have to be sold for perhaps £5 or £6, as much as £50 to get out new sets of patterns to meet a specification. I do not think any dynamo maker has ever had, in selling a dynamo for £1,000, to spend £2,000 or £3,000 in altering the patterns for any type when he only has an order for a few machines. I think that the manufacturers, by meeting together, not actually forming a combination but by forming a committee which would settle such points as outputs, accuracy, heating of armatures and so on, could do an immense amount of good; but the whole problem of standardisation is a far larger one than perhaps Mr. Sellon imagines.

Mr. Andrews.

Mr. L. ANDREWS: We users' engineers appreciate Mr. Sellon's paper as much as do the manufacturers. The present lack of uniformity in the various parts of the country is a great source of nuisance all round. At Hastings we have a periodicity of 100, and after hearing the discussion at the last meeting I went away with the idea that I should have to recommend my committee to scrap all our

existing machines and change to the 50 periodicity, which seemed to be the proper thing to go for. However, on thinking the matter over, I came to the conclusion that it was almost an impossible thing for us to do. I have taken the opportunity, since the last meeting, of discussing the matter with my chairman, pointing out that if a periodicity of 50 became the standard it would probably pay us in the long run to change, because we should be able to get our machines cheaper. I suggested that it would cost very much less to change now than it would in two or three years time. But his reply was that if we went to the ratepayers to ask for a large sum of money to replace our present plant, it would shake their confidence in the electrical undertaking. Mr. Andrews.

I quite agree with Mr. Sellon's suggestion that engineers should state more clearly the ends or performance they require for the plant rather than give details of construction; but if certain constructional details are not to be insisted upon, the manufacturers ought to take greater responsibility as to the behaviour of the plant. It appears that some manufacturers think they ought to be left to determine how the plant should be designed, and that it should then be handed over to the station engineer, who is to take the entire responsibility of its turning out all right. I do not think it is quite fair to blame either the users' engineer or the buyers' engineer for the present lack of uniformity in electrical engineering plant. If I may refer to the case of Hastings station, for instance, that has been more or less guided by manufacturers ever since its commencement about eighteen years ago. Up to the year 1890 the Hastings Company was supplying current to its consumers upon the old Brush series system, but the manufacturers to whom the engineers of the Company looked for advice told them that if they wished to keep pace with the times they must scrap their existing Brush series plant and go in for an up-to-date standard alternating parallel system of supply with 100 periodicity. The Hastings Company did so about ten years ago. Now we are told that we ought to change again. Again, although the Company went to a very heavy expense to change, they did not appear to get very much nearer the standard plant, for the transformers of 1892 would not work in parallel with the transformers in 1894, and the spare parts got for an engine in 1892 would not suit an engine built in 1894. I do not think that was the fault of either the buyer's or the user's engineer; it appears to be quite as much the manufacturers' fault. I quite agree with the principle of standardisation, but it is rather difficult to carry out on existing stations.

Mr. Stuart A. Russell: The author of this paper, in laying stress on the standardisation of sizes of units, has begun rather at the wrong end. Mr. Esson has already spoken of the variation of the speed of engines, but engine makers fixed their speeds and sizes of engines before the dynamo makers could come to any standards at all, and we certainly cannot ask them now to change. Let us say there is one maker who runs 10 per cent. faster than another; he cannot give up that 10 per cent. and so reduce the output of his engine by 10 per cent. to allow the dynamo makers to have standardised units. That difficulty will certainly stop any standardisation of sizes. With regard to small belt-driven plant Mr. Russell.

Mr. Russell. or motors, I do not think that the fixing of sizes will be a very great advantage. Every manufacturer will fix his own sizes and will make a certain number of machines; he will adopt and make a line of machines, but there is no advantage whatever in all manufacturers having exactly the same sizes; in fact, I think, on the contrary, the advantage would be all the other way. Of course one particular manufacturer will lose orders because his machines do not happen to fit what the customer wants, but that will be counterbalanced by his having the advantage another time. I believe, however, that the fixing of a standard electrical pressure would certainly be an advantage. We have, as the author said in his paper, accepted very readily the standard pressures for traction introduced from America. In doing so we have handicapped our own manufacturers, because it is common now to find in lighting stations machines which are to serve sometimes on lighting, sometimes on traction circuits. We get, therefore, quite commonly in specifications, say a 200-kilowatt machine which has to give that output at a voltage from 440 to 500 when running as a shunt machine on the lighting circuit, and also at 550 or 560 volts when running on the traction circuit. It is quite evident that that so-called 200-kilowatt machine is really a 250- or 260-kilowatt machine, but the engine is only sufficient for the 200 kilowatts. The user is buying a machine which is useless to him; he cannot make use of its full output, and, moreover, when he is running on the lighting circuit he is running it under decidedly unfavourable conditions as to the strength of the field. I have seen specifications where an overload was to be given at 440 volts, although probably that machine would never run at 440 volts when it was giving any current worth talking about. The net result was that that so-called 200-kilowatt machine turned out to be nearly a 300-kilowatt machine, but you could not get more than 200 kilowatts out of it because the engine limited the plant to that output. We may with advantage endeavour to get some uniformity between the traction and lighting voltages, as I believe that considerable saving in the cost of machinery would be made thereby.

There are certain other points not mentioned by the author in the paper. They are in a way minor points, but they offer much less difficulty, and might be standardised with advantage. The rating of machines is, for example, somewhat vague at present. If we can come to a decision that (say) a 50-kilowatt machine shall be one that can give 50 kilowatts continuously for a certain number of hours without more than a certain number of degrees rise in temperature at the end of that time, and if everybody understands that this is the test to be applied, we shall at least have gained something. Reference has been made to the Admiralty specification. Undoubtedly that did much to improve and raise the ideas of dynamo makers. When it was first issued it imposed somewhat more severe conditions than most of them were able to meet, and the Admiralty did indeed change their specification. They do, however, specify exactly as regards the rise of temperature, and our difficulty as manufacturers is rather that one engineer specifies a rise of 50°, another is content with

[illegible]

manufacturer.

Mr. L. B[illegible]: The question of periodicity has been [illegible] frequently in this discussion, and I have therefore prepared the [illegible] ing Tables. Table A shows the periodicity of the [illegible] Great Britain. I believe this has been published [illegible] but it is of some interest to have it before us with the [illegible] installed and the total kilowatts. Table B is of greater [illegible]

Mr. Birks.

TABLE A.—FREQUENCIES OF BRITISH ALTERNATE-CURRENT STATIONS.

Frequency ∿	No. of Stations	No. of Generators.	Total K.W.	Mean K.W. per Station.	Mean Power of Generators.
125	1	5	140	140	28
100	24	170	38,746	1,610	228
93	2	25	3,953	1,977	158
90	2	20	1,943	972	97
87	2	11	1,300	650	118
83	9	77	16,280	1,810	212
80	3	23	2,920	975	127
77	1	9	425	425	47
75	4	13	1,595	400	123
70	1	14	4,210	4,210	301
68	1	6	680	680	113
67	1	3	375	375	125
66	1	3	235	235	80
60	10	43	11,791	1,179	274
50	25	124	25,396	1,016	204
40	3	28	2,838	946	101
	90	574	112,827	1,253	197

the number of machines started at the various periodicities during each year since 1888. Before that date there were only five stations in operation. There are a few more in this list than Mr. Sellon has given, owing to the inclusion of those which are to be started this year. The noticeable fact is that periodicity is standardising itself very quickly towards 50 periods. For four years there has only been one station started with any periodicity other than 100, 60, and 50, and that is the Redditch station, which is quite small and which will probably follow Mr. Ferranti's advice and come over to 50 periods later, or to 60 at any rate, by slowing down. The question is really settling itself, therefore, and I think this will apply to a good many other classes of manufacture. I have included continuous-current stations in the table, and the very large number of 440-volt continuous-current low-tension stations now being started should be noticed. They are now preponderating very largely over the alternating and the high-tension Oxford system.

But this question of standardisation is such an important one, both to the manufacturer and consumer, that it should not be left merely to settle itself, and Mr. Sellon's paper on the subject is very opportune. Manufacturers would be consulting their own interests in the end to

Mr. Birks.

TABLE B.—CENTRAL STATIONS OF GREAT BRITAIN.

Year.	Alternating Current.					Direct.		Total.
	100 ∿	83 ∿	Other Frequencies.	60 ∿	50 ∿	H.T.	L.T.	
To 1888	2	2	—	1	—	—	4	9
1889	3	1	1	—	—	1	5	11
1890	3	1	2	—	—	—	2	8
1891	4	—	2	—	1	1	4	12
1892	1	1	1	1	1	1	4	10
1893	3	2	4	—	—	2	9	20
1894	3	2	4	1	3	1	5	19
1895	2	—	7	—	2	2	6	19
1896	—	—	—	3	2	—	9	14
1897	3	—	—	1	3	1	4	12
1898	—	—	—	1	3	1	11	16
1899	—	—	1	1	6	2	20	30
1900	—	—	—	1	4	—	41	46
Totals	24	9	22	10	25	12	124	226
No of Generators ...	170	77	160	43	124	92	698	1,364
Total K.W...	38,746	16,280	20,614	11,791	25,396	13,852	95,007	221,686
Mean power of Stations	1,610	1,810	938	1,179	1,016	1,155	765	980
Mean power of Generators.........	228	212	129	274	204	151	136	162

lay down definite standards for their special classes of goods, and to refuse to consider orders in which unnecessary variations from these standards were specified. And the Institution as a body could do a great deal to help in keeping these standards uniform by bringing the various manufacturers and consumers into consultation.

Mr. Levin.

Mr. A. E. Levin: In considering the effect of the consulting engineer on standardisation of plant, it may be perhaps interesting to look at what is happening on the Continent. The Continent is usually regarded as a kind of terrestrial paradise, where consultants cease from troubling and designers are at rest, but I think we shall find that, in spite of this, standardisation has not made very great progress there. To take a small but by no means unimportant matter, there is not even a standard system of screw threads in spite of the enormous advantage attained by the universal use of the metric system. Some manu-

Mr. Levin.

facturers use the Whitworth thread pure and simple ; some use an even diameter in millimetres with the nearest Whitworth pitch, while others have adopted a metrical diameter and metrical pitch, which is, after all, the most logical arrangement. Coming to electrical questions we find, although the periodicity is usually lower than was formerly customary in this country—that is to say, from 40 to 50 or perhaps 60—yet there is by no means uniformity in the exact value of the periodicity. In Switzerland alone there are stations running with 35, 38, 40, 42, 45, 48, 50, and 52 periods. I venture to differ from Mr. Esson when he says the question of periodicity is not a very important one. Although a difference of two or three periods may not affect motors or transformers at all, yet even the differences which I have mentioned, say between 40 and 52 or 55, are sufficient seriously to hamper the production of small motors in large numbers. or the stocking of such motors ready for work. The moral to be drawn therefrom is that standardisation must begin with the larger plant and not with the smaller. Every generator, at all events every large generator, which is built and turned out with an abnormal frequency creates a market for motors and transformers which will probably soon attain a much larger value expressed in total cost price than the generator itself, so that the evil, once started, will go on increasing. The tendency which is now so very distinctly shown by the tables prepared by Mr. Birks to bring down the frequency to a standard value of 50 is, I believe, a very healthy sign, and I have no doubt that it will make itself felt in the future.

Mr. Addenbrooke.

Mr. G. L. ADDENBROOKE : I think it was rather a mistake of the Institution to define frequency with great strictness, as there is not yet a sufficient amount of knowledge to enable us to define the frequency except in large ratios. I think that as we progress, and are able to go more carefully into the actions of alternating motors, we shall arrive at reasons which may cause us slightly, or even considerably, to vary frequencies from those now used. And although it may be desirable to standardise the frequency for the moment, yet it is very important to prevent that stopping progress. I cannot help thinking that many of the difficulties which have arisen, and which, no doubt, to a large extent have given rise to Mr. Sellon's paper, have been due to the fact which Mr. Evershed has referred to, namely, that the progress of the electrical industry in this country has not been a normal one. I have had occasion to go into the question lately, and the more carefully I have considered it, the more clearly it has become apparent that the industry in this country has been forced out of its natural lines by legislative action. This fact affects the question in many ways that do not seem, at first sight, to have anything to do with it. For instance, the fact that most of the work was practically thrown into the hands of municipalities led, at a certain period, to a large number of young men with very little commercial experience (probably not more than that obtained by going through works) being appointed as station-engineers. In the usual course of things, if there was a consulting engineer to start with, the Town Council, after a time, think that his services are superfluous, and *that* they had better trust their own engineer. Many of those young

Mr. Addenbrooke.

men have been very successful, and have begun to draw the specifications which they think proper, whereas there is no doubt that the drawing and handling of a proper specification are the most difficult things that one can well come across. As Mr. Hammond has said, the consulting engineers whom corporations seem to delight to consult are really what may be called putters-through of jobs on the most economical lines for their customers. Of course that is one view of the consulting engineers' position, but I venture to say that is not the view held in other branches of engineering, and that the experience of two or three centuries with other forms of engineering has shown that there is room for at any rate a certain number of consulting engineers who do know their work, and who are at any rate something more than putters-through of jobs on economical lines. A little later, when the interests of electrical undertakings get larger, and huge sums of money must be spent on them, perhaps there may be a greater inclination to look for real scientific and good advice on these subjects. On the other hand, the fact that municipalities with no consulting engineer have very little knowledge of electricity, and are liable to be swayed to a certain extent by those who most persistently put their claims before them, has led to a great deal of work in this country being done by men who I do not think would have been employed by shareholders if they were risking their own money in the undertakings, and some of these men have no doubt issued some very extraordinary specifications. I think the matter is settling itself to some extent, and although I think Mr. Sellon's paper will be most useful in calling attention to the question, it would be a pity for the Institution to go too far in endeavouring absolutely to standardise things. That is rather a manufacturers' question. There are numbers of things, as for instance sizes of shafts and bearings, which should be what they are specified. It is quite possible that Willans, and other good makers, make their engines with the bearings actually the size they are supposed to be, but that is by no means always the case. It would be extremely convenient if the sizes of shafts were really as specified, and not left to the man at the lathe to take his final cut-off to, say, within a 64th of an inch. Much work of that kind could be standardised very well, but by the manufacturers themselves, with, perhaps, the assistance of consulting engineers. But standardisation of principles, as other speakers have said, is a very difficult matter. As an instance: with regard to tramway work, Mr. Stuart Russell has spoken of standardising that with lighting work. I think there is little doubt if we, and the Americans also, were beginning tramway work all over again, but with our present experience, we should prefer 600 to 500 volts. It would lead to an enormous saving of copper and drop, and would have many advantages. The fact that Mr. Stuart Russell argues one way and I can at once bring forward an argument in another direction, shows how difficult the question is. The moment you begin to standardise, especially on matters of principle, you open up a field for illimitable argument, so that I think it is not advisable to go too far in that way, but to begin, as other people have said, at the bottom.

Mr. C. E. Grove: Several kinds of standardisations are mentioned Mr.

basis for empiricism if they had been artfully employed; but as electricity has escaped abuses I trust," etc., etc.

John Freke, F.R.S., who was elected Surgeon at St. Bartholomew's in 1729, is incidentally referred to in Fielding's well-known novel, "Tom Jones," as an authority on the subject of medical electricity.

It is now one hundred and fifty years since the beginning of Medical Electricity. During the whole of that time it has had to fight its way in the face of many difficulties, and the most serious of these has been the passive resistance of medical men themselves. The vitality which the subject has shown under adverse circumstances is most significant. Medical electricity advances steadily, and the progress during the last decade has been very great. The commercial application of electricity and its house to house distribution by Electric Lighting Companies have called into existence a large number of new instruments and new methods of treatment, and is helping the spread of the study of medical electricity by simplifying the means of obtaining the current when required. The accumulator has been of great service by affording a trustworthy source of currents for the use of surgeons in their galvano-cauteries and exploring lamp instruments. The discovery of the X rays and their application to surgery and medicine have also done good to the cause of medical electricity by bringing electrical apparatus into more extended use, and the founding of X-ray departments in hospitals gradually leads to the development of electro-therapeutic departments in places where these are not already in existence. Most of the London hospitals now have electrical departments, and these are of manifest utility. At St. Bartholomew's Hospital we have about six hundred cases referred yearly to the electrical department from all quarters of the hospital, exclusive of the cases for X-ray photography, the numbers of which are even greater. And the results of our treatment will compare favourably with those in any other branch of medical practice.

It is a little difficult to speak on a medical subject before a non-medical audience without incurring the suspicions of those who are always on the alert for signs of unprofessional behaviour, and there is no branch of medical practice upon which the fierce light of criticism shines more sharply than upon medical electricity. I shall therefore have nothing

to say on such matters as the relation of cases, statements of cures and so forth, which might be thought to be unsuitable to my audience, but will try to meet you on the common ground of apparatus and methods, and in particular I shall try to lay before you some of the difficulties and problems which arise in the course of our medical work, in the hope that some of them may be solved by the advice and suggestions of those who are here present.

From conversations which I have had at various times with engineering friends, I am disposed to think that the number and extent of the applications of electricity to medical practice are not generally realised by electrical engineers. Indeed, when I have observed any reference at all to medical electricity in the proceedings of this and of kindred societies, the reference has usually been one of disavowal and dislike. I therefore feel that in making the present communication to you, I am undertaking the task of trying to show that electrical applications have a large and legitimate field of usefulness in medical practice; that it is quite possible to practise medical electricity without thereby becoming an outcast, and that the advertisements of electropathic or magnetic appliances do not represent the position of medical electricity any more than, shall we say, Keeley represented all that was best and truest in electrical engineering.

If what I have to say to you may seem to be about trifling matters, I hope you will bear in mind that our unit is the milliampere, while yours is the kilowatt, and that the currents which we handle and use would make but a small figure if their energy were expressed in terms of horse-power. Nevertheless, in the small technical matters which have to do with the management of various kinds of small electrical apparatus, the medical man requires a thorough proficiency, because it is absolutely necessary that he shall be able to make his apparatus work. On that account we may appear, in certain matters, to take elaborate precautions which might seem to you to be hardly necessary. With our coils and batteries we require unfailing methods for increasing or decreasing the current sent through the patient, without stops or jerks. We have to deal with the electric light mains, either direct or alternating, or both. And we have evolved *for ourselves* a long array of contri-

basis for empiricism if they had been artfully employed; but as electricity has escaped abuses I trust," etc., etc.

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vances for utilising the public supplies of electricity for medical purposes. Small transformers, portable accumulators, resistances to provide slopes of potential, which can be tapped as desired for varying voltages, contrivances for using the mains for all sorts of medical purposes are all enlisted in medical work. The statical machine is also coming again into favour, and to use a statical machine one must know enough about its management to be quite sure that after a patient's arrival there shall be no awkward failure of the machine to excite. Otherwise we are likely to be condemned as not understanding our apparatus, and the patient may be lost. All these little matters can only be learned gradually, and through a course of failures and disappointments. And when they have been learned thoroughly, they constitute a very fair claim to the title of electrician.

The use of electricity in the production of hot-air baths with incandescent lamps or electrically heated coils of wire as the source of heat is a development of some promise; while, in the immediate future, we can see the approach of new methods of treatment by the light of the arc lamp. Each of these will demand a fresh extension of the field of electrical operations which the medical man will have to learn.

And now I feel sure that some of you are ready to ask what can be done with all these numerous forms of apparatus. You might be inclined to ask me, as a patient of mine asked me the other day, whether I had ever done anybody any good by electricity.

We will take the simplest things first. No doubt it is familiar to all of you that an electric shock produces a muscular contraction, but possibly you may not all be aware of the extent to which the study of the muscular contractions has been developed. The muscles and their nerves are tested by the application of the induction coil current, and by the direct current of a battery of cells; the effects at opening and at closing of the circuit, the comparison of the action of the positive pole with that of the negative, and the measurement of the current needed to produce visible contractions are all examined, and in this way a system of electrical testing has been devised which affords the most valuable indications in the diagnosis of diseases of the

nervous system. An important part of the work in the electrical department of a hospital is the testing and reporting upon cases of injury or disease of the various portions of the nervous system and of the muscles, and the accuracy of the answers given by electrical testing is something to delight one. For exactness and simplicity in its responses, one might compare electrical testing to the processes of measuring with a yard measure or weighing in a pair of scales; and numerous cases which are quite obscure until tested electrically, become as clear as daylight as soon as the test has been made.

The behaviour of a muscle under electrical stimulation is peculiar, and I think it may be useful to describe it. A simple shock, such as a single discharge of an induction coil or of a condenser, or a spark from the prime conductor of a static machine, causes a single muscular twitch, which within certain limits is proportionate to the energy of the discharge; the contraction lasts about one-tenth of a second. A rapid succession of shocks causes a succession of contractions which become fused so that the muscle enters into a permanent state of contraction which lasts as long as the stimuli are applied. Stimulation applied to a nerve causes contraction in its corresponding muscles, and when the stimuli are applied to the muscle itself, it is through the agency of its nerves that the stimulation acts.

With a continuous current the behaviour is different. Here there is a twitch at the moment of closing the circuit through the nerve or the muscle. The muscle then remains quiescent and almost completely relaxed, while the current still flows, and another twitch is produced when the circuit is broken. This is the sequence of events with the currents of about five milliamperes which are used for testing. With currents four or five times as strong the muscle enters into permanent contraction with continuous currents. These contractions at make and break may seem to recall the phenomena of electro-magnetic induction, but the analogy is more apparent than real.

In certain kinds of paralysis these reactions change, and all irritability of the muscle to coil currents disappears. Stimulation of the nerves gives no response either to coil or cells, but the contractility of the muscle remains for currents from the cells *applied directly*, and may be more easily

excited than in health, while the contraction itself changes in character from a rapid twitch, lasting one-tenth of a second, to a slow sluggish movement, lasting three times as long.

Stated briefly, the above are the observed facts of what is known as the Reaction of Degeneration. Its value depends upon the fact that it occurs only when the cause of the paralysis occupies certain definite portions of the nervous system. By its presence or absence we can therefore determine with great nicety the seat of the disease or injury. A point which is not yet explained is why the coil discharge should become ineffective on muscle which retains the power of responding to the battery current. What are the electrical differences between the two modes of stimulation?

Next as to electrical treatment. Progress in medical treatment usually moves along two lines. One of these is based upon experimental physiology, that is to say upon a study of the various processes in healthy tissues, and depends on the application of the facts observed to various morbid states. The other line of advance is by direct experiment in a more or less haphazard manner upon the sick. In medical electricity, as in medicine generally, both these lines have been followed. If we consider the first, we can apply the observed fact that electricity is a stimulus to certain living tissues, by asking how stimulation may be made use of in disease. The fact that electricity is a stimulus is easy to perceive in the case of nerve and muscle, and in the case of the sensory nerves of the body, and it is not difficult to prove that it acts in this way upon all living tissues, and the employment of electricity in disease is very largely an application of this process of stimulation.

Beard and Rockwell in the United States, and Débédat in France have shown experimentally that in young animals the rate of growth can be accelerated by suitable electrification. The former electrified daily two young puppies, and found that they grew faster than those of the same litter which were not electrified. Débédat in the same way proved an increase of weight in certain muscles of rabbits as compared with other non-electrified muscles in the same animals; the latter thus showed a local effect from localised electrification, the former a general effect

from general applications, and this division into general and local treatment is an useful one. Thus for general diseases one gives a general treatment, and for local diseases a local application. D'Arsonval, by calorimeter observations and chemical analysis of the expired air, has established the fact that electrification increases the activity of the tissue exchanges of the body. Capriati recently has shown by careful dynamometric researches that the application of electricity to the central nervous system in the form of a continuous current along the spine does undoubtedly increase the muscular power, and that applications to the muscles of a limb have the same effect. In the United States it is becoming fairly common for athletes to undergo electrical treatment when preparing for a contest. General electrification applied to cases of simple failure of nutrition, such as debility after illness, or debility of any kind, produces a rapid improvement in the condition of the patient. In rickets, which is a comparatively simple form of defective nutrition, electrical applications have been shown by many observers to have a very high value. The more complex forms of defective nutrition such as rheumatism, gout, and diabetes are not yet completely controlled by electricity, but indications are not wanting that in time good results may be expected. Already electricity is doing much for these conditions.

In the field of paralytic conditions there are certain strict limitations to the utility of electrical treatment, and it is here that electricity has lost credit quite undeservedly. People have expected electricity to work miracles, and because it could not do so have condemned it as useless altogether. When paralysis is due to some mechanical obstruction or destructive process in the nerve centres of the brain or the spinal cord, or when it is due to certain progressive degenerations in the quality of those parts, then electricity is powerless to help. So, too, when paralysis is due to a breach of continuity in a nerve trunk, electricity can do nothing until the surgeon has intervened and re-united the severed ends. In the latter case electricity comes in quite properly afterwards to promote the recovery of functions which had fallen into abeyance; in the former the surgeon cannot help, neither can electricity. Therefore it is *very important* to insist that in paralysis

there are cases suitable for electricity and cases which are unsuitable. Happily the number of those which are greatly benefited by electricity is a considerable one.

Another field in which electricity is useful is in the relief of pain. Oftentimes it acts by influencing the circulation in the painful part and relieving congestion and pressure in the blood-vessels. This I believe to be its mode of action in sciatica, lumbago and rheumatism, and in some neuralgias. At other times it seems to relieve a neuralgic pain by some direct influence upon the nerve-trunk in which the pain is felt. Effects upon the circulation are probably the important factor also in the relief of sprains, and in removing the chronic stiffness which may be felt in or around joints as the result of injury or disease. In this there is scope for considerable development. The good results which can be obtained are undoubted, although it is not generally known that this is the case.

Electricity can also be used to promote the passage of drugs into or through the skin, and this has a few minor applications in medical practice, among others for the introduction of cocaine to produce a local insensibility in minor surgery.

Electrolysis, again, is often useful in many small matters of surgery. It is used almost exclusively as a means of destroying tissue. Small tumours of various kinds can be very conveniently treated by electrolysis. The process is carried out by the introduction of metallic needles into the tumour, the products of electrolysis being thus liberated in contact with the tissue to be destroyed. The chief convenience is the ease with which one can regulate the strength of current, and the amount of caustic chemical liberated, in exact proportion to the work required to be done. So fine and so delicate an application can be made, that the root of a single hair can be destroyed without leaving any visible scar, and the removal of superfluous hair in this way is a matter for which electrolysis is continually applied. Electrolysis with copper or zinc anodes with the object of procuring the liberation of salts of these metals in the diseased tissues has been recommended abroad, but does not seem to have received much attention in this country.

One of the most encouraging points at the present time

in medical electricity is the improved quality of the scientific work which is being done in it. Last year, the French Government having declared the subject to be of public utility, a section of Medical Electricity was inaugurated at the Boulogne Congress of the French Association for the Advancement of Science. I attended the meetings of the section during the greater part of the Congress, and was struck by the number and high scientific quality of the communications which were made in it. It was one of the best attended sections of the whole Association. France, indeed, takes a long lead in the subject of medical electricity. They have at the present time three periodicals devoted entirely to the subject, and abundance of material seems continually forthcoming to fill the pages. One of them, the *Archives d'Electricité Médicale*, is quite indispensable to students of medical electricity, for in addition to its original matter, it provides its readers with abstracts and a bibliographical index which keep one in touch with all that is being done in medical electricity all over the world.

The progress in the small matters of detail, particularly with regard to apparatus, which has taken place during the last ten years, is considerable. I say ten years, because that represents the time during which my attention has been specially directed towards medical electricity.

It will be interesting to consider and compare the types of apparatus in common use to-day with those used formerly.

Electrodes.—The current is applied to the body of the patient by means of electrodes. These may be of the most varied forms, particularly with electrodes for internal applications. The cylindrical brass handles fitted with sponges and held, one in each hand, are obsolete or deserve to be, and for most external applications their place is now taken by a plate of flexible metal enclosed in wash-leather and a disc of metal also covered with wash-leather, and screwed into a wooden handle. The former is called the indifferent electrode, and serves chiefly to complete the circuit through the patient's body; the other or active electrode is the one which is manipulated and applied over the affected region. For testing, the active electrode is fitted with a closing key. Examples of electrodes and other forms of medical electrical appliances are shown upon the table. Bare metal must

never be allowed to touch the skin unless electrolytic, or painful effects are desired. Sores are easily produced in a few minutes by a few milliamperes of current if at any point the metal of the conductor touches the skin directly. For this reason some water-holding material, such as wash-leather, is always used to cover the metallic surfaces of medical electrodes.

The Battery.—The chief requirements in a medical cell are, that it shall need no attention, and will not spoil on open circuit. The past few years have seen the almost complete disappearance from medical work of open acid cells such as the Smee cell, the Bunsen and the bichromate cell. Formerly, when electrical treatment had to be carried out by means of ponderous oak boxes filled with cells of one or other of these kinds, the trouble and the dirt associated with them was enough to discourage all except enthusiasts. At the present day the Leclanché cell is the only type of battery which a medical man need consider, and even these are rapidly being abandoned, except for fixed installations, in favour of the modern, cheap, and convenient dry cell. With these small dry cells for currents of small magnitude and with a few accumulator cells for those medical purposes which require a current of an ampere or more, as for example for the heating of galvano-cauteries and the illumination of small exploring lamps, the medical man is sufficiently equipped, and is no longer compelled to handle and prepare caustic solutions. Large bichromate batteries still survive in remote districts for the occasional production of large currents, but they are every year becoming less numerous, as secondary cells and the means of charging them from dynamos become more general over the country. All this simplification tends very greatly towards the increased popularity of medical applications of electricity, because perhaps one chief cause of its neglect has been, hitherto, the trouble of the management of the apparatus.

The batteries needed for medical work divide themselves into two distinct classes, batteries for applying currents to patients for testing and treatment, and batteries for galvano-cautery and lamp apparatus. The former is essentially a physician's battery, the latter is more for the surgeon. Most of the surgeon's requirements are met by a portable accumulator of four cells, for the little surgical

lamps are for the most part eight-volt lamps, taking about an ampere; though usually they are overrun most cruelly. For galvano-cautery the currents average from five to ten amperes, but the cautery circuit has a low resistance and a pressure of eight volts is much more than is required. Sometimes the four-cell accumulator is arranged so that a switch will recombine it as two sets of two in parallel for cautery work, or else it is left as a four-cell battery in series, the volts being expended in a resistance. For medical work a battery is fitted with twenty-five to forty small dry cells connected in series and having wires led off from them to a circle of studs from which a moving pointer takes up into circuit as many cells as are required. It is usually fitted with a milliampere meter permanently in circuit and a commutator for reversing the poles, also with an induction coil driven by a separate dry cell. The average working resistance of the human body and skin is about 2,000 ohms when properly moistened with hot water. Salt or soda may be added to the water to reduce the skin resistance, but plain water is best, as it corrodes the electrodes less.

Next in importance to the battery of primary cells comes the induction coil. Indeed, if generality of use be considered, the induction coil should come first, as it is the form of electrical application which has the widest employment. The medical induction coil has developed in certain special directions, the chief requirement with such an apparatus being a means of careful regulation of its strength. Of the various ways of obtaining this regulation, the one best suited to our purpose is the plan of using a sliding secondary coil, which can be brought close to the primary or can be removed further from it, as desired. Much has been done of late years to improve the induction coil, and more has been written about the various effects to be got from coils of different sorts and construction. Attention has been given to the improvement of the vibrating spring or contact-breaker, and the best American coils are now fitted with two vibrators, one of slow speed and one of high speed. In the United States, where the construction of electro-medical apparatus has been much elaborated, it is quite customary to supply coils with several interchangeable secondaries. The same is done to a less degree by makers elsewhere. The *various effects* which have been ascribed

to different windings of secondary are best considered as being due to the very great differences in their self-induction, according as they are made with windings of great length and many turns, or of short length and few turns. The slower rise and fall of wave which is found with the high self-induction of the long coil of many windings has the effect of making the shock less sudden and less painful in its effects. So too in very long fine secondaries a large part of the volts are dropped inside the coil, and the E.M.F. at the terminals, though high on open circuit, may fall almost to nothing when closed through a comparatively low resistance. On this account very long coils with very high speed contact-breakers have been much written about as affording painless currents for internal applications, but in my opinion the painlessness is due to the fact that very little current comes out of them. For practical purposes, I have usually found it sufficient to use one secondary coil, which is tapped at one-third of its length, and so can give long coil and short coil effects from the one instrument. Medical induction coils are not fitted with condensers. When simple stimulation is required in the treatment of a case, the induction coil is probably the most convenient and cheap method of procuring it. The battery current has a superiority in certain things, for example it gives a wider range in degree and quality of stimulation; and certain living tissues respond better to battery currents slowly increased and decreased than they do to the sudden jerks of the coil. The intense effect of the coil on the sensory nerves of the skin makes it difficult to use coil currents of sufficient strength to penetrate to the deeper parts of the body, and for deep parts currents of large magnitude are necessary to make up for the weakening effect of diffusion.

The strength of current used in treatment ranges between four and forty milliamperes for the most part, though smaller and larger currents are sometimes used. The larger the currents, the larger should be the surfaces of the electrodes.

The measurement of induction-coil currents presents difficulties which have not hitherto been surmounted, and the rough comparisons which are made by means of a scale of millimetres at the side of the sliding secondary cannot be translated into units and cannot be trusted to be alike for

two consecutive days. Instruments which measure the mean current are of no use, because the physiological effect does not depend upon mean current but upon the rate of change and the maxima. The use of a sinusoidal current from a dynamo, to take the place of the induction coil, might enable one to evade the difficulty, but the dynamo current of the mains, in certain cases at least, produces such painful skin affects as to be very unpopular with patients. It is difficult to say why this is so, but the subject wants further study.

Possibly the use of condenser discharges, the condenser being automatically charged and discharged rapidly, might meet the difficulty of producing a current which would resemble that of the coil in its physiological action, and would allow of measurement. I would like to ask the advice of members of the Institution on this point: Would not the curve of discharge of a condenser have a close resemblance to the discharge curve of an induction-coil? Could not one arrange a condenser of small capacity such as a Leyden jar of diminutive size, and employ some very fine adjustment of spark gap for measurement and regulation? I have thought that in this way, using high voltages and small capacities, the disturbing factor of varying skin resistance would become comparatively unimportant.

Current from the Mains.—After its introduction into commerce the current of the electric lighting mains was quickly introduced into medical practice, and we make large use of it in the Electrical Department of St. Bartholomew's, which is connected with the mains of the City of London Electric Lighting Company. The current impulses from the alternating mains have a physiological action resembling those of the induction coil; that is to say, the effect upon nerve and muscle is to produce a permanent contraction so long as the current is applied. But it is superior to the induction coil in being a less violent stimulus to nerve and muscle by reason of the more even and gradual rise and fall of its waves. Larger currents can be borne than from the induction coil, and, judging from its effects in a long series of cases, it appears to be more thorough and more useful in its effects. Nearly all the cases formerly treated by the induction-coil at the hospital are now treated by the current from the mains, the *voltage* being lowered to suit the

requirements of the case (to about ten volts as an average), and indirectly we have gained largely in that the department is now free from the noise of eight or ten induction-coils all vibrating and buzzing at once. Formerly the effect of that noise during a long afternoon was most trying. There is one marked difference in the effect of the alternating current which limits its use, and that is that if applied in the ordinary manner through moistened electrodes to the surface of the skin, it has a peculiar, disagreeable, burning effect. The more thoroughly the skin is moistened, the less this is noticed, and when the current is conveyed to the patient through the medium of water, as in a bath, this disagreeable cutaneous effect disappears entirely. Consequently a mode of treatment by means of baths and the sinusoidal current has been developed to a very considerable extent, and with decided advantage to our patients. Large numbers of our cases are cases of paralysis of the upper limbs from injury or disease of the nerves of the upper extremities, and for these we use an arm-bath. The arm-bath is a stoneware trough, of suitable shape, having a metal electrode at each end, it is filled with warm water, into which the patient plunges the forearm and hand. The use of hot water as a medium for conveying electricity to a patient has many advantages. The current is much better borne, and therefore a stronger current can be used. Manipulation of the electrodes and personal handling of the patient is done away with, and the affected part is kept warm during the application. For these reasons we use it largely, and I continue to advocate its use as one which again is likely to increase the popularity of electricity among the medical profession, because it tends to simplify its mode of application. In addition to small local baths for parts of the body, we have a large bath, in which the whole of the body is immersed; and for general morbid conditions, as distinguished from local ones, the electric bath with the induction-coil current, or, better still, with the sinusoidal current of the mains, is an extremely useful contrivance. In that section of medical electricity which comprehends general applications for general systemic diseases—a field of work which is only now being thoroughly explored—the electric bath is perhaps superior to any other mode of applying general electrification. The other modes of doing

this are by the statical machine, or by the high-frequency and high-potential methods of Tesla and of D'Arsonval. The chief advantage of both these latter methods is that the patient need not disrobe; but on the other hand, the electric bath has the great advantage that the currents which are being used can be more readily measured and adjusted to suit individual needs. Chance very largely decides the choice of one or other of these methods of general electrification. Whereas the sinusoidal current and the bath suits one medical man best, the other forms may be more convenient to the conditions of practice of another one. The electric bath, unfortunately, has been rather under a cloud during recent years, in this country at least, by reason of its association with those peculiar "massage" establishments which sprang up so thickly in London a few years ago. Now, however, most of these establishments have disappeared, and one may venture to speak of the definite advantages of the electric bath without feeling that one's words may reappear in the columns of some journal in association with advertisements of undesirable houses. At St. Bartholomew's Hospital, excluding arm-baths, about one thousand baths, mostly with the sinusoidal current, are given each year, particularly for diseases like debility, rheumatism, sciatica, neuritis, lead-poisoning, and various forms of paralysis. No electrical department can be considered properly equipped without the electric bath, for in many morbid states its action is most valuable. The bath with direct current has also certain useful applications, although not so many as the induction-coil or the sinusoidal current bath. The direct current bath, local or general, is useful in the relief of gout, rheumatism, sprains, chronic inflammations, and generally as an absorbent for the removal of fibrous adhesions or thickenings in or about the joints and limbs. It is also indicated in painful states, when a varying current is too stimulating to be well borne, as for example, in acute sciatica, neuritis with pain, and so on.

The alternating current of the mains also lends itself extremely nicely to such uses as for galvano-cauteries and for the small exploring lamps used by surgeons, and where alternating current is laid on they now for the most part have small transformers *for use in this way.* Instruments

containing lamps and telescopes are now used for examining the interior of such cavities as the bladder and the stomach, which previously have been inaccessible to the sight; as well as for the illumination of more accessible parts, such as the throat, the ear, the nostrils, etc.

The arrangements at St. Bartholomew's for the distribution of our current from the mains consist of a transformer, tapped at intervals in its secondary winding and led to a row of binding-screws, from which any voltage, between half a volt and fifty volts, can be taken at will. The three rooms in which treatment is given are wired in three circuits as for electric lighting, and the voltage required can be switched on to any of the three rooms from the transformer. Thus we have at command low voltage currents for galvano-cauteries and small lamps, and higher voltage currents for applications to patients. We use three or four volts for cauteries, eight or ten for lamps, ten to twenty for the baths. Several of our old sledge-pattern induction coils with sliding secondaries are now converted for use as subsidiary regulating devices for the baths. I cannot say much of the use of direct-current mains in medical practice from personal experience. Although I have been instrumental in connecting three places to the lighting mains, I have never been in touch with direct-current circuits. The use of the direct current from the mains for applications to patients, and for other applications requiring low voltages, is carried out either indirectly by means of charging accumulators from the mains and using them, when disconnected, for the patients, or else by means of shunt resistances. The latter method is to provide a resistance of several thousand ohms, which is connected across the mains. The resistance is a bare wire coiled on a support, and is fitted with a travelling contact-shoe which can be moved so as to tap the windings at any point. The patient is arranged in a shunt circuit in parallel with any convenient length of the resistance. When only small currents are required, a lamp is arranged permanently in series with the wire resistance. The slope of potential which can be tapped at different points by the movements of the slider permit fine regulation of current in the shunt or patient's circuit. With shunt resistances of suitable magnitude current can be obtained for treatment, for working

induction coils, or for galvano-cauteries. In the latter case the waste is considerable, and it is my belief that an accumulator charged through a lamp would be much better, but in many cases the shunt circuit is preferred, in spite of its waste at the rate of more than a horse-power, whenever 10 amperes are wanted. Possibly something like a step-down induction coil might be devised for heating cauteries off the direct-current mains. One of the drawbacks of electric light supply is that those who have continuous current laid on cannot also have alternating. And so a medical man residing in a district supplied by direct current will have to generate any sinusoidal current needed by means of a motor dynamo. These instruments can be bought and are in use. On the other hand, a medical man supplied with alternating current will often sigh and wish that he could easily generate for himself a little continuous current. And here is a point which perhaps might be worth the attention of this Society, viz., the contrivance of some simple rotary converter which could be attached to a lamp socket in a house supplied with alternating current, and which would give out continuous current, sufficient to recharge a portable accumulator from time to time. Not much would be wanted, and perhaps it is just on that account that the instrument I have indicated is not easy to get; presumably it would not pay to make it. Still, a little rotary transformer, which would give out, say, an ampere at ten volts of continuous current, would be welcomed by many medical men who live in districts of alternating supply. The mechanical efficiency of the machine is in no way important, considering the smallness of the needs. That which would be important with such an instrument is that it could be left to run for periods of an hour or two at a time without needing its owner to stand over it and watch it, and that it would not become over-heated nor make a great noise.

The Statical Machine.—This form of apparatus—the first introduced into medical practice—is showing very decided signs of a revival. In the United States the statical machine is already very largely employed, and I am told that in New York alone there are no less than three firms busily engaged in turning out statical machines at the rate of two or three a week. Those who are *only* acquainted with the effects

produced by small statical machines can have no idea of the difference between small and large instruments of this kind. The effects produced by a large statical machine are most decided, and it is only necessary for one to experience them once to see that treatment by them is by no means a mere treatment through the imagination. The most apparent effects of the statical machine are the profound and peculiar cutaneous sensory stimulation which can be produced by it, and the forcible muscular contractions which can also be produced by it when the administration is in the form of sparks. Its special field of usefulness probably lies, first, in its action as a general excitant; secondly, in conditions of neuralgia and other superficial pains; thirdly, in the conditions of muscular pain. In all these cases it acts quickly and thoroughly. It is quite common to receive a patient stiff and lame from lumbago or muscular rheumatism, and to see him leave in ten or fifteen minutes quite free, for a time at least, from his lameness or his stiffness. All this promises to be extremely valuable. The difficulty of understanding how a simple electrification by the static machine can influence the body makes many of us disinclined to believe that there can be any effect; but after watching cases carefully for some time, I can now say with certainty that some direct action does take place. I have only had a proper static machine for a year and a half, and therefore still feel rather a beginner with it. A very interesting matter is that, whereas on the other side of the Atlantic the influence-machine which is used is invariably a modified Holtz's, on this side it is the Wimshurst which is considered the best. The American Holtz machine certainly has been developed into a most beautiful instrument; and, although it has one drawback when compared with the Wimshurst—that of not being self-exciting—that is a point so easily got over by means of a small accessory exciting machine in the corner of the case as to have no real importance. Size for size, I am disposed to believe that the Holtz gives a better output than the Wimshurst. It appears to be a more cheaply constructed machine, and needs no counter shaft nor cross-belts. Recently a large American Holtz machine has been presented to St. Bartholomew's Hospital; so we shall have an opportunity of testing and of comparing its

work with that of a large Wimshurst machine which I have recently had constructed for my own use. As a good Holtz machine is, so far as I know, a curiosity in this country, I shall have much pleasure in showing our machine to any members of the Institution who might wish to see it. The accessory apparatus and the technique of the statical machine have been very greatly simplified by the work of American physicians.

The application of high frequency currents to medical practice has not had much extension. In France it is used a little. The currents are taken from leads connected to the ends of the primary helix, and no secondary coil is used. An induction coil is generally used to charge the Leyden-jar condensers of the system. The applications are either by a sort of spark or brush discharge from one terminal to the patient; or the patient lying on a couch is attached to one pole, the other being connected to a sheet of metal under the couch. This is called the condenser bed. Finally the patient may be enclosed in the actual helix connecting the jars, and his body thus made the seat of induced currents by "auto-conduction." Its chief applications have been as a mode of general electrification, but the brush discharge is also applied locally to the skin, and has seemed efficacious in curing certain skin diseases.

Ozone.—The use of electricity for generating ozone for medical purposes is attracting some interest. It is not so much that these applications of ozone are entirely new, as that the apparatus is now becoming sufficiently improved to make its applications easier. But the rapid development of electricity in so many directions of late years has given medical men just at present so many fresh things to handle, that ozone in its medical applications is, as it were, waiting until some one has time to attend to it. The workers in medical electricity, in this country at least, are so few.

Perhaps the most striking of all the applications of electricity to medical work in recent times has been due to the discoveries of Professor Röntgen. The introduction of the X rays has revived very greatly the interest in medical electricity.

The Röntgen-ray work makes a very considerable ad-

dition to the work done in our electrical department at St. Bartholomew's Hospital, as it is in almost daily use for purposes of diagnosis in surgical cases. Physicians hitherto have paid but little attention to Röntgen rays, but its application to the diagnosis of diseases of the chest must be mentioned as perhaps one of the most promising things for the future. Certainly it is possible to diagnose pulmonary consumption and some other diseases of the chest more satisfactorily, and at an earlier state of the disease, by the X rays than is possible with the stethoscope; and this one point alone appears to me to be of the highest importance. For example, recently I saw the X-ray photograph of a patient's chest. She was suspected of having pulmonary disease, and was sent to one of my colleagues for an X-ray photograph; examination by the ordinary methods of auscultation and percussion had given an uncertain reply. But the negative taken with X rays showed without any possible doubt the presence of tubercles in the lung. If there were more time to spare I could go into the question of X-ray work more deeply on the grounds of its great development by medical practitioners, the localisation and stereoscopic methods of Dr. Mackenzie Davidson and others being singularly beautiful in their results; but I have the idea that most of us are a little sated with X-ray work just now, so I shall say no more except to refer to the extreme beauty of the fluorescent screen effects which are given by large static machines.

The President.

The PRESIDENT: The exceedingly interesting paper of Dr. Lewis Jones is now open for discussion, and I hope the discussion will not be so greatly prolonged that we shall not be able to have the opportunity which he has promised us of examining the apparatus he has brought. We do not often, in this room at any rate, see electrical apparatus of this class, and the chance that we have is the more valuable because we have Dr. Lewis Jones here to exhibit it. There are many points upon which I should like to ask questions of Dr. Lewis Jones. I will merely mention two. He used the word "electrification" in a manner somewhat different from that in which we electricians are in the habit of using it. We do not understand that, when a current goes through an object, that object is necessarily electrified. It is conducting electricity, but is not necessarily charged. By "electrification" we understand the object to be actually charged. Is there any use, then, in merely charging a person—putting him on a stool and electrifying him—without his having any current flowing into or out of him, or making discharges at him from outside? Is it the slightest use to

electrify a man without giving him a chance of any discharge, to electrify him and the things around him to exactly the same potential? If you put a man inside a Faraday cube and electrify the cube, is the person inside in the slightest degree affected, physiologically or pathologically? The President.

Mr. J. WIMSHURST: We all must be much indebted to Dr. Lewis Jones for giving us his large experiences in the therapeutic use of electricity. As he refers to the influence machine as a source supplying part of the electricity which he uses, I will limit my remarks to that form of instrument and its progress. Mr. Wimshurst.

About twenty-two years ago my attention was called to a Holtz machine obtained from Mr. Spottiswoode; it had 8 rotating plates and 8 fixed plates; it needed a drying compound inside its case, and an initial charge, even then its paper inductors would not retain a like charge, these and other difficulties gave much trouble, nevertheless it was a healthy offspring from the Nicholson Revolving Doubler, and deserved further attention.

To remove some of these objections I made up a machine having 12 rotating plates of 31 inches diameter, the dangerously cut fixed plates I substituted by rectangular slips of glass, and I connected together all the paper inductors on the one side of the machine by means of wire; this removed many of the objections, and it became more useful. About three years later Messrs. Paterson and Cooper made up some smaller machines. These machines were noticed in "Engineering" of the 6th of October, 1882.

In 1893 I made another machine of this type; it had two rotating plates of 42 inches diameter. I placed the fixed slips vertically, fixed metal sectors to the rotating glasses, then I added the brush contacts, the collecting combs, and the neutralising rods—the whole of the glass was efficiently coated with shellac varnish. This machine was self-exciting, its flow of current did not change, it needed no drying compound. It was noticed in "Engineering" of 5th of May, 1893.

I venture to recall the particulars of these machines because Dr. Lewis Jones has kindly invited the members of this Society to visit and inspect the large and expensively finished machine which his American friends have so liberally presented to St. Bartholomew's Hospital, and it seems to me that refreshing one's memory of the past is useful when judging of the present and the future.

It would be ungrateful, however, now to make any alterations in the beautifully finished present, but as time runs on I fear the drying compound and the exciter will be found troublesome. If so, I would suggest to Dr. Jones that he should have all the glass surfaces efficiently coated with shellac, that he should add about 12 sectors to each rotating plate, and suitable small brushes to the collecting combs, and that he could advantageously add additional slips of glass; he then will have all the good features introduced by me in the 1893 machine, and will find it to be self-exciting, to need no drying compound, and to work freely and well in any atmosphere.

Dr. Lewis Jones also mentions another machine which he has, in which all the glasses rotate oppositely, but he objects to the driving

Mr. Wimshurst. wheels, and the bands; but in a properly designed machine these should scarcely show, and as to durability, those in the first machine which I constructed twelve or more years ago are in about as good condition as when new; the durability is no doubt owing to my keeping them well oiled. You will perhaps remember the machine, for it was used at a meeting of this Institution by Dr. Lodge in his Lightning Rod Experiments, and by the late Professor Hughes in his paper upon Oil as an Insulator.

I may further add that this form of machine has had no drying compound, and for twelve years has had no repair; it has been much used, yet on all occasions it has freely excited, and has behaved in all respects perfectly.

General Webber. General WEBBER: So little time is left for the remarks which the hearing of this paper has prompted, that I shall confine myself as much as possible to one or two questions, which I wish to frame as intelligibly as I can to the ears of my audience. I should like to say that this meeting I regard as quite a memorable one in the annals of our Institution. Although we have once—many years ago—had a paper read to us of a somewhat similar character, I do not think that within the walls of the Institution of Civil Engineers has a paper ever been read in which it may be said that the engineer and the physiologist have met.

Dr. Lewis Jones has happily helped my analogy by comparing the work, as a "repairer," of the medical practitioner and the engineer, and also by referring to common ground as covered by the similar use of apparatus and a similarity in methods.

In respect to the relief of pain by electricity in one way, and to the causation of pain when it is employed to destroy tissue in another way, its use is analogous to that of the application of heat (say) above 90° F, which at one temperature soothes, at another stimulates, at another injures.

This aspect of the question, together with that connected with the use of currents either continuous or alternating, requires consideration which is not permissible in the time at my disposal.

One question that has been raised in my mind by the speaker refers to the use of the word "stimulus." Does the physiologist or the medical practitioner and user of electricity mean that electricity is only a stimulus to the organic structure, or is it an auxiliary to something which already exists within it? In his most interesting description of the electric communication or electric testing by means of the nerves, every telegraph engineer in this room must have been reminded of his daily work in "localising faults." It is done in a telegraph system of conductors, instruments, etc., by means almost identical with those which the author described as used by him for the localisation of injuries to the organic structure. The necessity arises out of an injury or degeneration through disease, which leaves behind entire or partial paralysis, caused by entire or partial severance or disintegration of the nerve. The test by means of a current is made. In a telegraph circuit a fault may be due to either complete, partial, or intermitting disconnection. The testing galvanometer shows a full or partial "response"

[redacted]

or no response at all. In the case of the telegraph circuit continuity is completed by "earth." We have not been told how it is obtained in the organic structure, unless it is through water in which the structure is immersed, or on the surface of the skin when moistened, which otherwise when dry has high insulating properties. General Webber

So in a similar way, I think, our electrical distribution engineer may ask the author whether his work does not find an analogy within the human frame—that is to say, generation, distribution, and utilisation of energy.[1] Remember I am speaking entirely as a layman and as an engineer, and therefore I am only anxious that the author will give us some idea if, in using the word "stimulus," he means that he is or is not adding something which is auxiliary to a system of generation, distribution, and utilisation of energy which, I think, we may assume is going on always within our bodies. And that particularly in connection with the involuntary work or expenditure of energy that is going on in the circulation of the blood, an illustration of which is to be found in the estimate of Helmholtz that the heart can raise its own weight of 9 oz. through 20,250 feet in one hour, and also in the well-known fact that the weight of the blood is about one-twelfth the whole weight of the body. There must be some generation of energy; there must be some conduction of that energy to the heart to enable it to exert that force. A study of that mechanical involuntary work that is always going on has seemed to me to point to one great fallacy in the medical or physiological books which I have read, and that is that the heart is a pump.

The tests made by physiologists by inserting tubes in an artery and measuring the pressure are no proof that all the pressure emanates from the walls of the heart. As an engineer, one protests against the assumption. As an humble student of nature, one finds everything to contradict it. Nature does nothing unmechanically. The concentration in one place of the work against the load is unmechanical if the work can be distributed. We engineers are learning, by placing motors all over a factory, to distribute work in the expenditure of the energy which has been generated at a central place. I believe that a really careful and scientific study of this question by physiologists with an engineering turn of mind, would show that, of the work done in maintaining the circulation of the blood, the greatest expenditure of energy is at the periphery, *i.e.*, in the skin, where the larger quantity of blood has to find its way through a tissue or membrane situated at a vast number of points in the skin, where the red and blue capillaries meet, and where there must be expenditure of energy which, when taken together (and measured in "ergs"), must be greater than that exerted at the heart.

Even already the medical treatment of defects in the circulation by what is called the Nauheim baths is winning its way, and is understood and admitted by experts in it, to be entirely mechanical in its effects.

[1] On page 3 of a pamphlet by Major Crompton, entitled "The Fitting of the Bicycle to the Rider," will be found an allusion to the "food energy," its "distribution," and its work in "repair" of waste. I hope he will, on his return from South Africa, continue *the pursuit of* this question.

General Webber.

I would put that into words thus: The balance in the share of work to be done has been upset. One part of the structure—*i.e.*, the heart—is being overworked. The treatment stimulates the skin to take up its proper share (probably at each capillary).

I have seen in a medical treatise describing the circulation of the blood a description of what goes on mechanically, which showed the necessity for a mechanical study of these questions. The writer bases his illustration on the fact that the united cross-sections of all the capillaries is "several hundred times that of the aorta." The movement of the blood through closed tubes and vessels is illustrated by the movement of water in an open channel with various widths, depths, and sections, and without reference to the influence of fall, friction, or atmospheric pressure, and utterly unscientific conclusions are drawn for the instruction of medical students. This book is a text-book published in the United States, and later in this country. Otherwise, in its own science, it is apparently eminently correct.

This may be going a little outside our subject for the moment, and I shall not pursue it further, but I hope my remarks may lead others to make it their study. The only place in which I have traced any allusion to work done in the organic structure by means of electrical energy—there may be many others, and my research may have been very deficient—is a reference to electrolytic action said to be going on in the capillaries on each side of a membrane through which the blood corpuscles have to pass, which membrane, I think, Sir Michael Foster tells us no microscopic power has yet been able to analyse, the positive action being on the red capillary side and the negative on that of the blue capillary. Whether the effect of the action is endosmic, or stimulating, or propelling, or is described as negative dialysis is, I believe, as yet obscure to the physiologist. The engineer can, from the mechanical point of view, have little doubt that the propulsion of the fluid is universally assisted. If work is going on (amongst others) at every point where capillaries exist, there must be a universal system of distribution of energy to carry on the involuntary work of the circulation, as well as to do any other work that has to be performed in the capillaries and elsewhere. I will only further remark that anything which brings the engineer and the physiologist, or those who use electrical energy for the purpose of medical treatment nearer to one another, anything which brings their minds in contact, must be of use to our fellow-creatures. That the reader of this most interesting and valuable paper has to-night brought us much nearer to understanding the use of electricity for medical purposes than we have ever before had the opportunity of being brought, is a statement with which you will all agree.[1]

Mr. Mudford.

Mr. F. J. MUDFORD: I should like to suggest to Dr. Jones that a possible means of measuring the current represented by the top of the

[1] I would add a remark (since the meeting), namely, that if the nerves are *poor* conductors of electricity, and if, at the same time, they conduct energy, may it not be that they are in some way also electrical accumulators which are perpetually in a condition of charge and discharge?

wave to which he alluded would be to set over the pointer of an ordinary milliampere meter to a point on the scale where it would be just kicked off. It would be a little troublesome in use, but I have used that method myself. Mr. Mudford.

Sir HENRY MANCE: There is one point which has not been referred to by Dr. Jones, and that is the polarisation that takes place in the human body under the passage of a current. I remember many years ago making some experiments to ascertain the resistance of the body from one wrist to the other. I found that the results I obtained were much higher than what they ought to be, but when corrected by the formula for eliminating the effect of polarisation they came out somewhat as follows: I tested two natives, one of whom had a resistance of 1,300 ohms, and the other 1,200 ohms. The resistance between the wrists of an adult European tested at the same time under similar conditions was somewhat less, being 900 ohms only. There was polarisation in each case. Sir Henry Mance.

Professor J. PERRY: I speak as a Philistine on this subject, but I should like to say that I am very glad to think that medical men are beginning to speak about the great evil of the earthing of the return in the wiring of shops and houses. With regard to the charging of accumulators, I, in common with many people, have wanted a small voltage supply for charging an accumulator. Why not do this? Suppose your house is wired for 200 volts, you could easily get a lamp of lower voltage which you could put on in series with your accumulator. Have that lamp going when you want to charge your accumulator, and at other times put on the ordinary lamp. May I tell General Webber that we believe there is something the reverse of electrolysis going on in the animal machine? The animal machine, which consumes fuel and gives out mechanical energy is, as most of us believe, an electrical machine. It cannot be a heat machine unless the second law of thermo-dynamics is inapplicable. Its efficiency is pretty high—quite forty times higher than it would be if it were a heat machine working within such low limits of temperature. It may be that the second law of thermo-dynamics is evaded, for we know that exceedingly small beings are able to evade it; and possibly they need not be so small as to be of molecular size to do so. The chances are that it is an electrical machine, and, in fact, I think we know pretty well how the fuel is converted into electric and other forms of energy: it is a gas battery. I wish I had time to dwell upon this and give my ideas as to the real mechanism by which the thing occurs. I have been trying for years to do in a model what Nature does so very easily in the human body, but it is not easy to imitate. Professor Perry.

I will refer to one other matter. Last year, at Baden-Baden, I became acquainted with a gentleman very well known to many English specialists—Dr. Schliep. I was greatly astonished to find that for twenty years that gentleman had actually been making experiments—it is not often one finds a medical man making experiments of any kind—on atmospheric electricity. He asked me to try to invent a simple instrument which would give him the sort of measurement that he wanted; which could be sold to medical men quite cheaply, and this,

Professor Perry. he thought, might induce all medical men, or a great number of them, to make observations. As it was he had been using a gold-leaf electroscope, and was able to show whether the potential was plus or minus, and whether it was much or little. But really it was most astonishing the sort of result that he obtained. He told me he knew fifteen hours beforehand when certain classes of patient would come in crowds to him. If there was positive electrification nearly every one would be fairly healthy—some cases of neuralgia would present themselves—but when there was negative electrification he knew that all sort of nervous and depressed people would be coming to him for relief. As a rule there is positive electrification when the weather is dry and negative when the weather is wet, but it is not a high but rising barometer that accompanies the positive electrification.

Mr. Coffin. Mr. W. H. Coffin: It seems to me that the great drawback in the past has been the fact that the physician has not been (nor is he yet) a physicist, nor have they met in the physiologist, who ignores the question of therapeutics. I well remember the occasion, referred to by General Webber, in this room many years ago, when Mr. Preece, as he then was, made a great point of the fact that even those medical men who had devoted themselves to the study of electrical treatment were ignorant of such things as an ampere or a volt, it being in Mr. Preece's mind that electricity was prescribed regardless of amount and quality; as if you were to send a patient into the pharmacy to take as much as he wished of any particular medicine recommended. There will always be a difference between the measurement of anything approaching accurate current strength or electrification and the measurement of a dose of a drug taken into the system. The measurement of effect must be the difficulty in the medical use of electricity. It must be, as Dr. Jones has told us so clearly, that in modern medical practice electricity when not used either to replace the surgeon's knife by electrolysis of tumours or pathological growths, or to replace the caustic paste, is employed more for a general systemic than for a local electro-stimulation, which has somewhat failed and disappointed us. Much of this, apparently, as has been pointed out, is due to our imperfect apprehension of the conducting power of the skin. The insulation of the skin varies so enormously in different circumstances and in different individuals, that we really do not know what we are doing when we imagine we are sending a current through the body, applying both poles to the cutaneous surface. I think that any one who has systematically used electricity will endorse what Dr. Jones says in his encomium upon the electrical water bath, the great comfort, the great ease and simplicity and beautiful results one gets from that must certainly be made a good deal of. But there is this difficulty, that in the electric bath you really do not know what current your patient is receiving. You know the maximum current which he might have, and therefore there is a safeguard, but when you consider he is surrounded by a conducting medium at varying temperatures it is very difficult, and it may be impossible, to know what takes place exactly. So that those who have derived valuable results from electric baths have almost been led to consider that it was almost a superficial effect, and not a

very deep one; but upon this I do not for a moment presume to dogmatise. But to go back to the fundamental point, it will appear that in physiological laboratories, where we look for some light upon the therapeutic action, electricity has been used only to diagnose, to test, as an irritant, excitant, stimulant in other researches, and although we know somewhat how muscle and nerve will react with electricity, and that certain contractions and vital actions are accompanied by electric changes, we have never been able to invert the process as to what effect electrical charge or conduction has upon metabolic changes or physiological processes, and we have fallen back upon the statement that it appears to be an excitation, a stimulation, from which, in terms of energy, very small causes seem to produce singularly large results, but how it happens we do not know. In confirming what General Webber has said, it is a very useful and hopeful thing to have a discussion of this kind here. I well remember the previous one, and I am very much impressed by the advance which is apparent in the paper, and in the discussion to-night. Mr. Coffin.

Captain W. P. Brett: The author has referred to X-Ray work, as far as it has explored the human frame, but he has not mentioned whether these rays have any curative effect. My curiosity was excited not very long since by seeing what appeared to be a remarkable series of photographs of a case of lupus in the face. The photographs were of the patient taken at intervals of a week. He was subjected periodically to the X-Rays, and the results were most remarkable in the disappearance of the lupus within a comparatively short time. I would like to ask the lecturer whether he knows of any other instance of curative work by means of X-Rays. In reference to the author's wanting a means of charging small cells; that want was felt very keenly in the recent Egyptian campaign, where the X-Rays were first used in warfare, and it was met in this way: A tandem bicycle was found, and a small dynamo; the bicycle was mounted to run that dynamo, and the cells were kept charged. With direct current, as Professor Perry has pointed out, there is no difficulty; and with alternating current, especially where efficiency is of no account, we can put in a small motor, connected with a small generator. Captain Brett.

Mr. W. M. Mordey: May I suggest that for small currents we should use thermopiles? They could be easily produced for such purposes at a reasonable price, if there were a large demand for a type that could be used with the ordinary gas supply, and made to give an ampere or so at a few volts. Mr. Mordey.

In regard to the question of apparatus, it is to be wished that some engineers who had time and opportunity would take up the design of apparatus of the kind exhibited in illustration of this paper. There has been practically no change, for example, in the design of the Rhumkorf coil since Rhumkorf invented it. It is true that, in attempting to improve an apparatus of this kind, one finds that the original designers knew more than one supposes, and it seems at first perhaps difficult to improve them, but I am quite sure that the Rhumkorf coil has lasted long enough in its present form. To refer, for example, to the very nicely got-up and polished *instrument* exhibited here, the laminated

[redacted]

Mr. Mordey. pole-piece is carefully short-circuited by a solid block of metal. Here, where the magnetism is wanted to go in and out as easily as possible, every possible precaution has been taken to prevent it from doing so. The block that moves is a solid piece, and the pole-piece, instead of being laminated so as to work with the smallest possible current and with the greatest rapidity, is made solid. In many respects the Rhumkorf coil might be improved by any of us with experience of designing, and with time to take the thing up. I have no doubt that kind of criticism could be applied with force to most of the apparatus sold by opticians.

I am glad the President has asked the author to explain what is meant in medical circles by "electrification." It is to be noted that the terms so often met with in medical papers dealing with electrical matters are not used here. The author has avoided the words "Faradisation" and "Galvanisation," and a number of other words which electricians find in medical works, but not in any other kind of electrical literature. I do not know whether General Webber worked out the horse-power of the heart, but in the example he gave it is only about four-thousandths of a horse-power.

Mr. Trotter. Mr. A. P. Trotter: I have never seen one of the aluminium one-way cells which only allow current to pass in one direction. Such a cell might serve to charge an accumulator with an alternating current. Perhaps somebody will give us some more information about it. I should like to ask if Dr. Jones can tell us what it is that he wishes to measure with his induction coil. Is it the voltage, or is it the milliamperes, or the millicoulumbs? He has stated that the different kinds of alternate currents—from the coil, from the alternate current mains, and so on—have different effects. It may be the top of the peak of the curve which is giving the result, and the total coulombs might be a very small factor in the question. The number of milliamperes is, I believe, usually measured, and this is naturally the only consideration which affects the question with continuous current. It is a particularly interesting subject to me, for I happen to have followed Dr. Jones's work for the last twenty years, since I was studying physiology with him, and I have watched the important progress which has been made. I asked his permission just now to ask him a question. If you try to hold out your arm straight from the shoulder for some time it becomes exceedingly painful. From an engineering point of view you are using force, but not doing any work. Physiologically I believe you are doing work. But that peculiar tiredness, I believe, can be almost wiped out in a very short time by a certain application of electric current. It occurs to me that when one comes home very tired after a day's work, not muscular work, some of that tiredness might be removed. I should like to ask Dr. Jones to tell us something on this point.

General Webber. General C. E. Webber: May I ask Dr. Jones if he will try and combine the answer to my question with that of Mr. Trotter's, because I think the same answer will apply to both.

Mr. Walker. Mr. S. F. Walker [*communicated*]: I should like to offer my hearty congratulations to the author, and to those who are working with him.

on the great advance which has been made in the application of electricity to medical and surgical work since the last occasion on which the subject was brought before the Institute; and still more on the grasp of the subject which Dr. Jones himself appears to have secured. Mr. Walker

When the Institution—then the Society of Telegraph Engineers—met at the Health Exhibition, the late Dr. Stone, who had been working at the subject for some years, gave a lecture, from which it was evident that medical electrical practice was then in a very empirical state, and the knowledge of electricity possessed by some, even of the ablest men of the medical profession, very small. From Dr. Jones's paper we are able to see that all that is changed.

One cause of backwardness in those days was the crude form of the apparatus employed, and the great difficulty of keeping it in working order. Doctors who used electricity in their private practice liked to have a portable apparatus that they could carry about with them. But this necessitated small cells, which were, and are even now, though much improved, very troublesome to maintain. To produce a current of any strength, even measured in milliamperes, although for a short time, fairly large cells, and some of the more powerful oxidising agents, with all which their use entailed, had to be employed. The advent of electricity supply has changed all that, and it is very gratifying to electrical engineers to find that the great London hospitals have so quickly taken advantage of the currents ready to their hand.

But there is another cause for the backwardness that I fear still exists, notwithstanding the great advances which have been made by Dr. Lewis Jones and other leaders of his profession; and that is the want of collaboration between the two professions. Each profession stands at an enormous disadvantage when approaching problems connected with the ground occupied by the other. The very nomenclature of each must be largely a *terra incognita* to the other! And even where a member of either profession is able to study the principles of the practice of the other profession, sufficiently to enable him to deal with the work in hand at the moment, he cannot have a grasp of the subject like the man who has made the science a lifelong study, and hence will necessarily miss many important lessons, and will take longer in working out each problem, than if he were assisted by a member of the other profession. On the other hand, there should be few secrets in the working of the organs of the human body that Nature could refuse to disclose, when examined by a joint commission of the two professions. Unfortunately, there appears to be considerable jealousy on the part of large numbers of the medical profession as to the intrusion of any outsider within their sacred grounds. We may fairly hope, however, that this also will disappear. Electrical engineers have been ready to take up every subject into which electricity could be introduced, so that probably medicine and surgery will follow in due course.

The author asks us to help him to solve several problems. He asks why the induced current from a coil behaves in a manner different from the continuous current, when applied to healthy and diseased muscles, but he omits to instruct us as to the working of muscles and

Mr. Walker. nerves, under ordinary conditions, when electricity is not in evidence. In the remarks which follow on this point, therefore, it must be taken that I am merely suggesting methods of investigation, rather than offering a solution of the problem.

The author tells us that when an induced current from the ordinary make and break coil is applied to a muscle, the latter gives a twitch lasting for the tenth of a second, the contraction becoming permanent, as long as the current is applied, when the shocks succeed each other sufficiently rapidly. On the other hand, a continuous current of about 5 milliamperes produces a twitch on closing, and on opening the circuit, the muscle remaining quiescent while the current is passing, after the first twitch on closing; but that when continuous currents of 20 to 25 milliamperes are passed through the muscle permanent contraction takes place. Again, when paralysis—of a limb, I presume—is present, the muscle will not respond through its nerves—I presume through its trunk nerves—to either the induced current from the coil, or the continuous current, but that the muscle will respond to the continuous current when applied to it directly. I gather, however, from the statement on page 351, that it is the weaker form of continuous current to which the muscle responds, by giving a slow twitch. As the author remarks, this method of testing must be of great value in diagnosis; but he asks us to state why the nerves and muscles behave as they do. I believe that we can answer the question when we have all the conditions before us. I believe I am right in saying that all the muscles are controlled by a system of nerves, emanating from either the brain or the spinal cord, and ramifying throughout the system, like the branches of a tree, or, say, the distribution network of an electricity supply, and that when a muscle is to operate a message is sent from the brain, or by reflex action from the spinal cord, along the nerve to the muscle; and, further, that paralysis of a particular muscle or group of muscles, consists in the inability of the nerve controlling the muscle, or the group of muscles, to transmit the message. It is not known, I believe, how the message is transmitted by the nerves; but it is known that if the nerve is severed, that portion lying beyond the parting is cut off, and the control of the muscles controlled by it is lost; and that if a nerve is pressed, crushed, by a foreign body, such as an abnormal growth of any kind, its ability to transmit messages to the muscles it controls is impaired, and may be suspended. It is known also that the message may be imitated, I believe, by tickling the exposed end of the nerve, by applying heat to the nerve, or by applying electricity in the manner described. We may fairly assume, then, that the nerve message is transmitted by a physical force, a mode of motion, like heat and electricity, into which heat or electricity can be transformed. In every part of the body also there exists a complete system of blood-vessels in duplicate, connected at one end by the very fine network of the capillaries, and at the other by the heart. These two sets of blood-vessels (the veins and arteries) lie, usually, side by side, or very close to each other. In the former set the blood is streaming back slowly, at a *uniform* rate, while in the latter set it is being forced outward by the heart in pulsations of 60 to 70 strokes per

minute. Now, although every part of the body will transmit electric currents, in the inverse ratio of their proportions, I believe that the major portion of any current which passes through any part of the body, omitting that transmitted by the moisture on the skin, will be carried by the blood-vessels. When we pass a current through a portion of the body, say through a limb, or through a set of muscles, we perform the following operations:— Mr. Walker

1. We deliver to the nerves in the line of the current a certain quantity of energy, which they are able to transform into what may be termed nerve conduction.

2. We create a magnetic field within the body, and around it, but chiefly around the principal blood-vessels.

3. We charge a condenser within the muscle.

4. In virtue of the presence of this magnetic field, we generate E.M.F's. in the fluids moving in the blood-vessels, and these E.M.F's. will be:

a. Opposite to each other, by reason of the fact that the fluids, the conductors, are moving in opposite directions, and

b. While that generated in the veins will be a steady E.M.F., that in the arteries will be pulsating.

But the behaviour of the muscles when induced and continuous currents are applied to them, gives us further information as to the nature of the nerve current, or rather as to the conditions under which, apparently, it is generated, which I think will enable us to get nearer the cause of the difference between the action of the two currents, to which I have above referred in quoting the author's remarks on the subject. It would appear, then, that the excitation of the nerves controlling the muscle is connected either with the creation and recession of the lines of force, constituting the magnetic field created within the body, or with the charge and discharge of the condenser. The explanation of the permanent contraction of a muscle under the influence of a continuous current of a certain strength may be as follows: While a current is passing through a muscle, currents pass through the blood-vessels, and a steady E.M.F. is created by the blood passing in the veins, and a pulsating E.M.F., in the opposite direction, created in the arteries. At the commencement of each pulsation, we shall have, in the artery, a feeble imitation of what takes place with the current from the induction coil, and when the circuit of the continuous current is first closed, viz., a disturbance of the magnetic field in the neighbourhood, and of the electrostatic conditions. If this is so, it is only necessary for the current to be of a certain strength for these successive disturbances to be of sufficient magnitude to cause the same permanent contraction, as the delivery of successive currents from the induction coil does. The line of investigation would appear, therefore, to be to measure the smallest current, or the smallest E.M.F. necessary to excite each particular nerve, and to find out what actually takes place during the passage of currents, which are steady outside the body. It should also be noted that the increased E.M.F. present when a larger current is passing may have something to do with the matter. Evidently, a long series of careful measurements is required. There is another point

Mr. Walker, worthy of investigation, viz., Does the energy expended when a muscle is contracted, come from the brain or from the muscle itself; and how is the transformation effected from the nerve to the muscle, or how is the message passed on?

On page 352 of the paper reference is made to the application of electric currents increasing the rate of growth of particular animals, and of particular muscles. No measurements, however, beyond the increased rate of growth appear to have been made. It is to be presumed that the increased rate of nutrition was due to the well-known property of electrical endosmose, the property in virtue of which the passage of liquids through a porous body is more rapid, when a current of electricity is passing in the same direction.

I would suggest to the author that this is a portion of the subject well worth following up with accurate measurement. The rate of acceleration of the endosmotic action per square millimetre of membrane, and per tenth of a milliampere, should be carefully measured for each important membrane in the body, and for membranes in various stages in health and disease, and I venture to suggest that when this has been done electricity will be used very much more for restoring health, where its loss is due to imperfect action of the organs of secretion. The task is a difficult one, but probably not more so than many others the medical profession have undertaken, and I do not think it will be found an impossible one.

Much may be accomplished in the way of measurement, and many "pointers" obtained, by experimenting on porous earthenware, and upon membranes taken from animals, after various lengths of time. More will be done, however, when the medical profession recognise that the human body is an electrical apparatus, or a system of apparatus, just as a telephone, or electric light or power service is, and that its circuits are all to be mapped out electrically, so that when an E.M.F. of a given value is created between any two points or surfaces it will be known that a certain current strength is passing through a certain membrane, and should be doing certain work, or through a certain duct, or bone, &c., and that certain E.M.F's. exist at certain points within the body. I shall, no doubt, be told, as I have been before, that this is impossible. It is not—it is only difficult. An outsider, looking at one of the street testing-boxes of the telegraph service, would imagine it to be impossible to know the current passing in each wire; yet, as we all know, the engineer of the postal telegraph service can tell, at any moment, not only how much current is passing through each wire but how much is passing through each foot of the insulating envelope of each wire.

The author has gone a long way in this direction, as he realises that the current disperses after it has passed inside the body.

I have indicated, in the above remarks, necessarily in a somewhat imperfect form, the thoughts that have occurred to me on reading Dr. Lewis Jones's paper, and I hope that he may be induced to continue his investigations, with, I am sure, every assistance the Institution can give him.

Dr. *Lewis Jones*. Dr. Lewis Jones in reply said: I have tried to be as careful as I

Dr. Lewis Jones.

could with my terms before this audience, and I recognise the objections to the use of the word "electrification" in the sense of general electrical applications. I will tell you how one comes to use it. Patients are sent to me from the out-patients' rooms or the wards to be "electrified" or to be "galvanised," and so one has got into the way of using as a general term the word "electrification" for all electrical applications. There is another word, "electrisation," which we might perhaps make use of instead. I am very glad that Mr. Mordey notes the fact that I have not used the word "Faradisation." I constantly endeavour to do without that word and to teach the profession not to use it. I prefer to use circumlocution, and speak of treatment by the coil, and treatment by the cells, and, if possible, always avoid "galvanisation" and "Faradisation." There is also the word "Franklinisation," and I read recently in a French journal the word D'Arsonvalisation! General Webber, in his very kindly remarks, has practically raised the question whether electricity is related to vital force. Is a nerve impulse an electrical impulse? No doubt one can find traces of electrical action whenever any chemical or other change is going on, but whether the electrical changes observed in living nerve and muscle are mere wastes, or whether they are of essential importance I cannot say. I will say simply this, keeping closely to facts, that the rate at which a nerve impulse travels down a nerve is totally different, in order of magnitude, from the rate at which an electrical impulse passes along a conductor, and that a nerve stimulated by an electrical current first translates that electrical impulse into a nerve impulse which then is passed on to the muscle at the rate at which impulses travel along nerves, viz., about 30 metres per second, so in that there is no superficial connection, so far as I can see, between vital force and electricity. To go deeper into the question involves one in difficulties which I would prefer this evening not to consider. The question of polarisation in applications of electricity to the body which Sir Henry Mance has raised is a thing which we observe continually in electrical applications. I was interested to notice that he described the testing of the resistances of several people, one a European and the others natives. I assume, therefore, it was in some hot country, and it is interesting to observe that the European had the lower resistance, because in hot climates it has been observed that the European is likely to perspire more than the native, and the resistance of the skin is largely a question of moisture or dryness of the surface.

Professor Perry's suggestion that the body is an electrical machine I am not qualified to handle. With regard to Captain Brett's remarks, there is no doubt that X-Rays have an useful therapeutic effect not only on lupus but on other skin diseases; but I fear that there are practical difficulties in the way of his suggestion that we should charge our accumulators with a bicycle and a little dynamo. With regard to thermopiles, I was sorry that the Cox thermopiles disappeared from commerce. I had great hopes that there was something there which would be useful to us, but I have had no opportunity of using one. There is also some uncertainty as to the life of thermopiles. How long do they last? You can still buy in this country a Gülcher thermo-

Dr. Lewis Jones.

pile, but it only gives current at 3 volts, and several would be needed to charge an accumulator of four cells, which is the type we mostly use.

Most of the apparatus on the table is German. English instrument-makers do not pay much attention to electrical medical apparatus. A doctor has to pay for his apparatus out of his earnings, and his position is entirely different from that of one who buys for a public company and can afford good things. English instrument-makers can make the most beautiful apparatus, but we cannot afford their prices, and they are not well acquainted with our requirements. We have therefore to take what we can get, and we can buy ready-made German apparatus, and those we use and make the best of. Mr. Trotter has suggested the aluminium cell as a means of obtaining direct current from alternating mains. I spent much time one summer trying to make one which would do what was wanted, but it seemed unable to work against several secondary cells. After two or three hours a pitting action began to take place, the aluminium cell became hot, and in the end I had to give up the attempt. I could not make it work, and although long papers have since been read on the subject I fail to see in those papers any clear statement that it was possible with the aluminium cell to effect the particular transformation we want. I should be glad to know if somebody has succeeded and is prepared to sell the perfected apparatus; but I am afraid it does not work. With regard to the question asked by Mr. Trotter respecting electrical applications to dispel fatigue, I have mentioned a new paper on the subject by Prof. Capriati, a physiologist in Italy, which has been brought out with very good dynamo-metric tracings and measurements. He has shown that electrical stimulation, that is to say, a constant current passed along the spine, whether upwards or downwards, increases the muscular force for a day or two after the application, also that electrical stimulus applied to the nerves and muscles of the arms does the same thing for the arms. Whether it is a question of improved circulation or whether there is a direct effect upon the activity of the nerve cells I cannot say, but that there is a direct refreshing effect of that kind in stimulation of the brain and the parts around the brain, and the upper parts of the spinal cord seems undoubted. People who are treated for other things will sometimes notice an improvement in their general health, after applications to the head and neck, which is quite apart from the object which is desired in their treatment. For example, one has sometimes to try and relieve some kinds of deafness by electrical applications to the region of the auditory nerve. One pole is placed in front of the ears, and the other pole is at the back of the neck. These people, even if they get no benefit to their hearing will often speak quite confidently of feeling an improved general condition. I remember some time ago being told by a lady that she had felt much better in herself after a course of treatment for deafness, and that in spite of the fact that the deafness itself was no better. There was an instance where, quite unprompted and unsuggested, she had recognised a feeling of good health to be associated with the electrical applications.

Then I have been asked what we want to measure in our induction

coil applications. What we really want is to be able, in testing, to reproduce to-morrow the conditions of a test applied to-day. Many factors are concerned in the testing of nerve and muscle. If you are trying to see what is the minimum current which will make a muscle contract, you will get different results and different minima on changing the self-induction of your circuit. Self-induction in a circuit makes a larger current necessary for the minimum stimulus. That self-induction clearly would act by slowly retarding the rate of growth of the current. Therefore, I think we may say what we want to know is not only the value of the current, but the shape of the curve of its rise and fall. Dr. Lewis Jon[es]

No one has given me exactly what I wanted with regard to the condenser to replace the induction coil for testing purposes. I have a notion that given a condenser of known capacity charged to a known voltage, the curve of discharge could be plotted for different conditions of external resistance for which it is discharged, so that by its means we could reproduce exactly the conditions of any previous test. I would have liked to hear something on that point; and also as to the modifications in that curve which are produced by increases or decreases in the resistance through which it is discharged; for example, where the external circuit is of 1,000 or 2,000, or 4,000 ohms, also whether by raising the voltage, and using a smaller condenser to match, one could diminish the differences in the shape of the discharge curves which were produced by differences in the resistances.

The PRESIDENT: I have now to move a hearty vote of thanks to Dr. Jones for his paper. Personally I think we have had one of the most interesting discussions of the whole Session. The President.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Members:

Herbert Edward Neville Appelbee. | William Benison Hird, B.A.

Associate Members:

James Coats. | Matthew McAuley Gillespie.
Gerald Hart Jackson.

Associates:

Allan Falkner Beach.
Walter Bryan Cheetham.
Henry Lewis Jones, M.D.
William James Albert London.
Robert Burns Maccall.
Sarsfield William Martyn.
Cecil Nathan.
E. Grey Scott.
James Boyd Shield.
William Wallace.
Alfred Tufnell Yates.

Students:

Edward Carter.
Richard Vincent Lynn.
Duncan Reid.
Fitzroy Owen Jonathan Roose.
William Stewart Ross.
Charles Percival Tonge.
Arthur Clemment Wilmot.

GLASGOW LOCAL SECTION.

[illegible] Section, [illegible]

THE PROBLEM OF ARC-LIGHTING FROM [illegible]-VOLT SUPPLY.

By W. B. SAYERS, Member.

The adoption of [illegible] electric supply in Glasgow [illegible] welcomed by all [illegible] who are anxious to see a system established on a permanent and secure basis.

The pressure adopted by Mr. Chamen is the highest permitted by the Board of Trade to be used on private consumers' premises, unless when special precautions prescribed by the Board of Trade are adopted and their permission to use the higher pressure obtained.

There is no doubt that the pressure now adopted reaches the limit at which accidental contact with the circuit by the human frame involves little or no risk of serious shock, and at which the better class of insulating materials and types of apparatus which have been developed for interior work are safe and reliable.

With the enormous growth of the demand for electric energy, and the ever-widening area over which it appears, the increase of pressure was inevitable, unless stations were put down at frequent intervals all over the city, or some system of high-pressure distribution with transforming apparatus was adopted. For the reasons already given we may, I think, regard the pressure now adopted as final—at any rate during the era of the present types of consuming devices—and I take this late opportunity of congratulating Mr. Chamen on having gone the full length of the Board of Trade tether in determining the pressure for the new supply stations for Glasgow, and of wishing him safe and speedy relief from the great and almost innumerable difficulties which the change of pressure over an already large system involves.

When incandescence lamps were first introduced, they were generally adapted for a pressure of about 50 volts; and two or more run in series according to the voltage of the circuit. In order to be able to turn out single lamps,

it was necessary to provide alternative resistances to waste the energy which would be consumed by the lamps if burning, and keep the pressure on the other lamps constant. The adoption of 250 volts as the pressure of supply for private consumers has landed us in the same difficulty with regard to arc lamps. With 100-volt supply difficulty existed, but to a much smaller degree; enclosed-type arcs burning singly across 100-volt circuits were a satisfactory solution of the problem as regards the convenience of having every lamp independent of the remainder, and though the energy consumed for a given result as regards actual illumination is much greater in the 100-volt enclosed-type arc as compared with the ordinary open-type, yet the practical effect with the 100-volt enclosed-type is often quite satisfactory. Moreover the enclosed-type lamps have the great advantage of burning about twenty times as long (more or less) as those of the open-type with one supply of carbons.

With the 100-volt supply, when open-type lamps were preferred, they could be run two in series, and if one only was used with a resistance in series the waste of energy was only 50 per cent.

But when we come to 250 volts, the conditions of arc-lighting must be described as extremely awkward and unsatisfactory. It is true that enclosed-type lamps are to be had which burn singly across a 250-volt circuit, but any which have come under my observation so far must be described as mere apologies for arc-lamps, the energy consumed being very great for the amount of light given out, and the colour of the light being unsatisfactory.

We must therefore use two enclosed lamps across 250 volts, and put up with a 50 per cent. loss if we only wish to burn one; or if we wish open-type lamps, we must consume energy sufficient for four or five lamps or multiples of those numbers, wasting the difference between this and the energy really required for useful lamps. In fact, with arc-lights the consumer is deprived of the power of economising by turning off lamps not actually required, or turning "on" only when required, and the exercise of this power of control in incandescence lighting experience has shown to be the very essence of economy.

At this point it will be convenient to say something about the relative merits as regards light-giving qualities

of open- and enclosed-type arc-lamps. This I am able to do in a more definite way than I could otherwise have done, owing to the kindness of Mr. Chamen in allowing me to make some comparative observations at the arc-lamp testing-shop, Port Dundas, and in making which I had the advantage of Mr. Lackie's co-operation. Comparisons were made between 50-volt open-type arcs, 100-volt enclosed-type, 250-volt enclosed-type, and groups of incandescence lamps, all consuming approximately the same amount of energy. The lamps compared were fitted with opalescent globes such as are used in the great majority of lamps in use throughout the city, the enclosed-types being fitted with obscured inner and outer globes, and the open-type with a globe such as is used in the street lamps; thus the comparison is a simple practical one. No attempt was made to measure actual candle-power, but the 10-ampere open-type arc with opalescent globe was taken as the standard of comparison, and the light given by the others is stated in terms of that given by the 10-ampere open-type lamp.

Two methods of comparison were used; the grease-spot and the shadow methods, the light being taken as proportional to the square of the distances—in the one case between each source and the point where the grease-spot became invisible, or nearly so, and the other to the square of the distances between each source and a pencil throwing shadows of equal intensities; the results are given in Table I.

TABLE I.

	Open-type Arc.	Enclosed-type Arcs.		Incandescents (new lamps), Clear Globes.			
	5 in Series. S.R. = 4 ohms. C = 10 Amps. Watts = 500	2 in Series. S.R. = 12 ohms. C = 4 Amps. Watts = 500	Single. S.R. = C = 2·75 Amps. Watts = 680	16, 16-c.p. C = 4·4 Amps. Watts = 1100	16, 16-c.p. C = 4·4 Amps. Watts = 500.	31, 8-c.p. C = 4·5 Amps. Watts = 1120.	31, 8-c.p. C = 4·5 Amps. Watts = 500
Relative Luminosity	1	0·475	0·1	0·68	0·31	0·75	0·333
Do., do.	3·25	1·54	0·325	—	1	—	1·07

NOTE: Voltages across lamps and resistances = 250.

From the above table it appears that open-type arcs of the sizes mentioned are twice as effective as enclosed-type, and $3\frac{1}{4}$ times as effective as groups of new incandescent clear-globe lamps. It is true that, owing mainly to the greater time which enclosed lamps will burn with one trimming, they are sometimes to be preferred, and are in fact in considerable demand by the public, but I question very much whether their popularity would be anything like what it is if open-type lamps could be used in single parallel or even two in series, and the public was informed of the fact that something like twice the amount of light was to be had from open-type lamps for the same cost for electricity. Of course, when the consumer is told that if he has open-type lamps he must have four or five in series and that he cannot control them singly—at any rate without having to pay for energy for all, and when this state of matters is compared with only two enclosed arcs in series, coupled with the advantage as regards duration of carbons, he is most likely to decide in favour of enclosed lamps.

I will now enumerate the disadvantages of the 250-volt supply from the arc-lamp users' point of view, and afterwards describe some means of mitigating them as far as possible. And first :—

OPEN-TYPE ARCS.—1. Not fewer than four or five lamps can be fixed, and greater numbers must be multiples of these numbers, or if less numbers are fixed the energy consumed must be equal to that required for four or five, or for multiples of four or five ; thus if there are five lamps in series, five will have to be turned on, though only one is really necessary, and if six are necessary ten will have to be turned on.

2. With four or five lamps in series the disturbance due to one faulty lamp affects all the others on the circuit ; hence flickerings and irregularities will be four or five times as frequent on the average as would be the case if each lamp were independent.

3. All lamps in one circuit must be of the same size ; that is, must take the same current.

ENCLOSED-TYPE.—The three disadvantages described above with regard to open-type apply in a greatly diminished degree to enclosed-type; but, on the other hand, this may

be said to be nearly or quite counterbalanced by the smaller amount of light produced by a given expenditure of energy. There is the further disadvantage in many cases of inferiority of colour.

Now I come to the means available for mitigating these disadvantages, but first I remark that :—

The 250-volt enclosed arc would meet all the difficulties if it only did not lack the essential quality of giving light, but seeing that it only gives about one-third as much as a group of incandescents and one-tenth as much as an open-type arc consuming energy at the same rate, it may be dismissed at once as unsatisfactory ; also

Multiple-carbon lamps capable of burning satisfactorily with a sufficiently small current would also meet all the difficulties, but unfortunately they are not in the market.

Where a sufficient number of lamps is required two modes of meeting the difficulties present themselves—first the obvious one of using a continuous-current step-down transformer to change the supply pressure from 250 volts to a suitable one for burning lamps in single parallel, and, second, the use of an arrangement which I have devised, but not so far put into practice. This arrangement comprises the use of what I call a "ganger" switchboard. It is very simple. You run a separate pair of cables to every lamp, bringing the ends to a convenient spot and terminating them in a suitable double-plug connection. Within reach of these connectors are rows of contact blocks or springs arranged four or five in series, as the case may be ; four or five additional plugs are provided, which are connected to resistance coils each suitable for replacing one lamp. The lamps wanted are plugged into circuit as required, filling up the groups of contacts in succession, the resistance plugs being used to complete the series circuits.

With a large number of lights distributed throughout a warehouse, for example, the number of circuits turned on will be the minimum possible for the number of lights in use, and consequently this system would ensure the greatest economy possible in a series system as regards consumption of electricity.

Its disadvantages are :—

1. Means of signalling to the switchboard, such as

speaking tubes, bells or telephones, must be provided at convenient points, and some person at or near the switchboard must be charged with the duty of plugging lamps in or taking them out as required.

2. All the lamps must be of the same size, and must be adjusted to work one with the other in any combination. (At present lamps intended to burn in a series are adjusted together, and marked so that they may be kept together.)

This ganger switchboard arrangement is not entirely novel; something of the same kind has been in use for some years by the Midland Railway Company, at St. Pancras, where circuits of forty or more lamps in series are built up of groups of lamps by means of a plug switchboard. The arrangement was, I believe, originated by my brother, Mr. J. Sayers, under the superintendence of the Midland Railway Company's chief electrical engineer, Mr. W. E. Langdon.

The best, and indeed I think the only really satisfactory mode of dealing with the question—where the number of lamps required warrants it,—is the use of a step-down transformer giving on the generator side a pressure suitable for working the lamps in single parallel. This presents the following advantages:—

Lamps may be turned on or off as needed, thus bringing arc-lamps into line with incandescence lamps as regards independent control and consequent economy.

The size of each lamp may be fixed with reference to the particular area it is required to light.

The number of lamps fixed will be just as many as are required—neither more or less, and obviously one or more lamps may be added or taken out, as compared with the necessity for adding or deducting a circuit of four or five.

The voltage across the lamp terminals may be adjusted to give the best possible results, instead of being controlled by the necessity for burning a certain number in series across a circuit not specially designed for arc-lamps.

The disadvantages of the transformer are obvious; namely the first cost, and the waste of power in the transformer. These two disadvantages, however, in my opinion, by no means counterbalance the advantages enumerated above; but with regard to the waste of power, I suggest that this *might* fairly be born by the Supply

Company—in our case by the Corporation Electricity Supply Department. I commend this suggestion with the hope that it may not be considered unreasonable by those who have the fixing of the rates of charge. The public, I think, have the right to expect that they should have reasonable facilities for using arc-lamps in the most convenient and economical manner, paying only for the light-giving current, and it seems to me that the Electricity Department may fairly be asked to consider whether, if the consumer is prepared to make the capital outlay necessary for a transformer to reduce their pressure to one suitable for arc-lamps, they should not meet him by putting their meter on the low-tension side. Companies and Corporations using high-pressure distributing systems always put their meters on the low-pressure side and charge only for the useful current.

The arc-lamp transformer would only be turned on when lamps were actually required, instead of wasting power throughout the twenty-four hours, as is the case in high-tension alternating-current systems.

When a step-down transformer is used, a very important question is: What is the best voltage to adopt for arcs in single parallel? In considering this question, it occurred to me that notwithstanding the fact that the voltage required across one arc to give the best results is pretty narrowly defined, yet those engaged in the development of the modern arc-lamp have no doubt been influenced to a certain degree by the necessity for producing lamps which would burn two in series on 100-volt circuits, and that, if arc-lamp makers had a perfectly free hand as regards the voltage they could have across the lamp terminals, they might prefer to adjust their lamps for a somewhat higher voltage across the arc than that commonly adopted, and to use a little more steadying resistance than is absolutely indispensable.

Accordingly I have asked several of the leading makers and users of arc-lamps to favour me by replying to a set of questions, with liberty to make use of the information they give in this paper.

The questions were replied to categorically by one maker only, the Brockie-Pell, the other firms and companies addressed giving information in their own way, and I prefer

[redacted]

to give the information in the form in which I received it. The questions submitted in each case were those answered by the Brockie-Pell Company :—

Brockie-Pell Arc Lamp.

Q. (1) *What voltages would you use by preference for open-type arcs of* 8, 10, 15, *and* 20 *amperes respectively?*

Ans.—

8 Amp.		10 Amp.		15 Amp.		20 Amp.
$42^v - 44^v$	...	$42^v - 44^v$	...	$43^v - 45^v$	...	$45^v - 47^v$

Q. (2) *What would you consider the* BEST PRESSURE *for open-type arcs in single parallel, having regard to*—

(a) *Steadiness.*
(b) *Effectiveness; that is, useful light for power consumed.*
(c) *Colour.*

Ans.—

	8 Amp.		10 Amp.		15 Amp.		20 Amp.
(*a*)	$60^v - 65^v$	...	$60^v - 65^v$	...	$60^v - 65^v$	...	$65^v - 70^v$
(*b*)	$50^v - 55^v$	...	$50^v - 55^v$	...	$55^v - 60^v$	...	$60^v - 65^v$
(*c*)	$60^v - 65^v$	...	$60^v - 65^v$	...	$60^v - 65^v$	...	$65^v - 70^v$

Q. (3) *What voltage would you use across the arc in each case, or how much resistance would you put in circuit with each* 8, 10, 15 *and* 20 *ampere arc respectively?*

Ans.—

	8 Amp.		10 Amp.		15 Amp.		20 Amp.
(*a*)	$42^v - 44^v$	...	$42^v - 44^v$	...	$43^v - 45^v$	...	$45^v - 47^v$
(*b*)	$42^v - 44^v$	...	$42^v - 44^v$	...	$43^v - 45^v$	...	$45^v - 47^v$
(*c*)	$44^v - 47^v$	...	$48^v - 48^v$	...	$46^v - 49^v$	...	$48^v - 52^v$

Crompton & Co., Limited.

"*Q.* (1) We find, from long experience, that about 50 volts should be allowed for each arc-lamp. We do not think there is much difference between two lamps in series on 100 to 110 volts, or four in series on 200 to 220 volts. Five in series will run quite well on 250 volts, and in fact we

have lamps running five in series on 235 volts, but this latter is cutting things rather too fine. We have also lamps running 10 in series on 460 volts, and they are behaving very well, but it is necessary to use a starting resistance in order to avoid violent pumping when the lamps are switched on. The necessary volts per lamp for steady running slightly decreases as the number of lamps in series is increased, but it is a very safe rule to assume that 50 volts are required per lamp.

"*Q.* (2) For lamps in single parallel.

"(*a*) 55 volts is the lowest circuit pressure we could recommend for steady burning.

"(*b*) The above pressure also gives best efficiency, that is useful light for power consumed.

"(*c*) The colour is affected by the length of the arc, and it is found that the light is at its best when lamps are adjusted to take about 43 volts across the arc. The colour becomes tinted with purple or violet if the volts at the arc are raised from 45 to 50 volts. A few years ago lamps were run with 50 volts across the arc, which resulted in unsteady burning and also a more or less coloured light.

"If 50 volts are used at the arc, 55 would be too little for the circuit volts. These should be raised to some 60 to 65; but we do not think that this is ever done now, at least not in the United Kingdom.

"*Q.* (3) We adjust all our lamps, 8, 15, and 20 amperes, so that they will burn with from 42 to 44 volts across each arc. We recognise 43 as *the* figure."

THE GENERAL ELECTRIC CO., LIMITED.

"*Q.* (1) We prefer using 42 volts for all arcs from 8 to 20 amperes.

"*Q.* (2) The best line pressure for lamps in single parallel we consider to be 55 volts for 8-ampere arcs, 50 volts for 20-ampere arcs, allowing proportionate voltages for intermediate currents.

"Our answers to Nos. 1 and 2 also answer No. 3."

MESSRS. P. R. JACKSON & CO., LIMITED.

"The best pressure for our direct-current 'Jackson-Mensing' arc-lamps with any current, and having regard to either steadiness, effectiveness, or colour, is 38 volts. The amount of resistance required in circuit depends on the voltage of supply. We do not quite understand your first query, but may say that the greater the voltage and the more lamps run in series, the better the burning of our lamps."

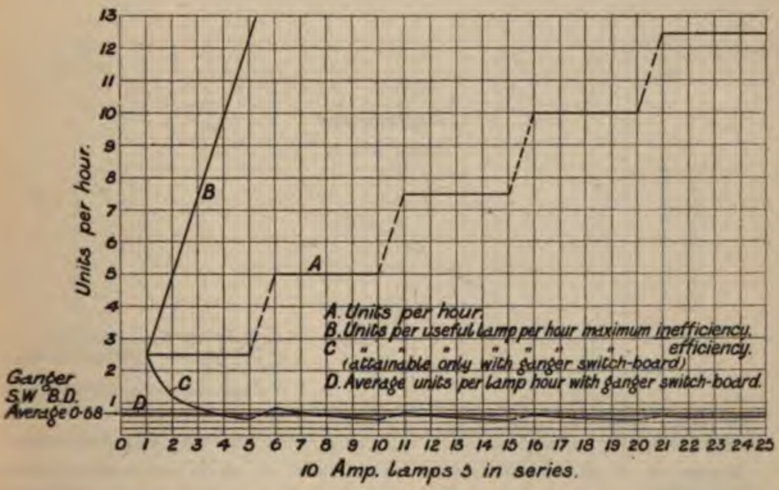

FIG. 1.

MR. LANGDON'S EXPERIENCE.

I can certainly say without hesitation that 42 volts is a very uneconomical pressure for arc-lamps.

"If you can get carbons that do not flare, you can work up to certainly 50 volts with a production of light greater than the proportional increase of volts.

"In practice, however, we find 46 to 48 volts to be the best volts to maintain across our arcs.

"There is another disadvantage in using such a low voltage arc as 42, in that a comparatively small irregularity in the feed puts the lamp nearly out.

"I think that 47-volt, 10-ampere arcs about the best unit that can be adopted.

"With our 210-volt circuits we burn four such lamps in

series with from two to three ohms in circuit, according to the distance the lamps are away from the feeding point."

Fig. 1.—The curve A shows the units per hour consumed as successive circuits of 5–10-ampere lamps in series are turned on. The curve B shows the maximum B.o.T. units per lamp-hour; *e.g.*, one lamp only is required, but five have to be turned on; or two lamps are necessary and they are on different circuits, so that ten lamps must be turned on—thus the consumption is at the rate of 2½ B.o.T. units per

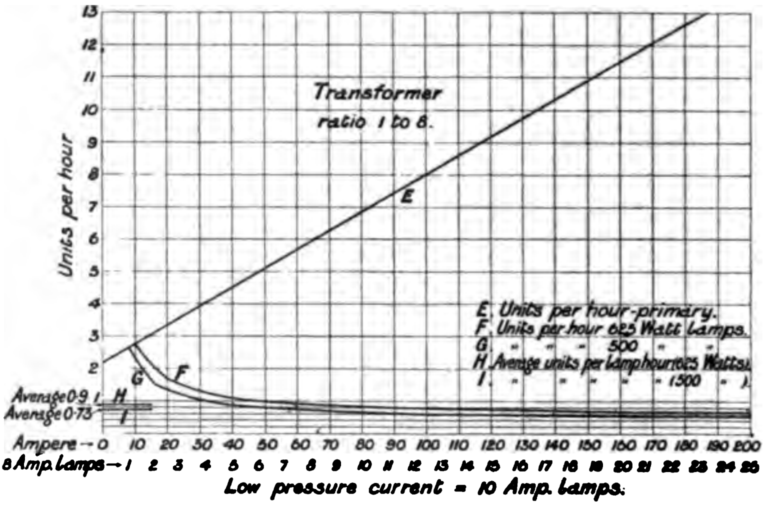

FIG. 2.

lamp. The curve C gives the B.o.T. units per lamp-hour if the circuits turned on is the minimum possible for number of lamps required. This is obviously possible only with the "ganger" switchboard, or some equivalent arrangement. The curve D shows the average B.o.T. units per hour for 500-watt lamps with the ganger switchboard.

With a simple five in series distribution the average B.o.T. units per lamp-hour will lie between the curve B and the curve C, *i.e.*, between 2·5 and ·68 (taking a maximum of 25 lamps), and will be nearer the higher or the lower figure according to the degree to which it may or may not be practicable to so arrange the lamp circuits that those lamps required at the same time are upon the same circuits,

Fig. 2.—The curve E shows B.o.T. units per hour taken by the primary of a step-down transformer coupled on primary side to 500-volt supply and having a ratio 1 to 8 ; F shows B.o.T. units per lamp-hour (absorbed on primary side) for 625-watt lamps, and G for 500-watt lamps.

H is the average for 625-watt lamps.

I is the average for 500-watt lamps.

DUBLIN LOCAL SECTION.

INAUGURAL ADDRESS BY THE CHAIRMAN.

Delivered February 22, 1900, by

PROFESSOR G. F. FITZGERALD, F.R.S.

THE APPLICATIONS OF SCIENCE—A LESSON FROM THE NINETEENTH CENTURY.

I FEEL very much honoured by having been placed in the position I now occupy and by having to deliver this opening address to the Dublin Branch of the Institution of Electrical Engineers. I believe that we are one of the first of the branches that has developed into the meeting stage of our existence, and may congratulate ourselves on having passed through our larval transformations safely and rapidly and on our having been the first to emerge into an imago.

The action of the parent Institution in founding these local branches is worthy of our grateful commendation. We are left perfectly free to develop our own life untrammelled by any rules except such as we would ourselves have necessarily chosen to govern our actions. We have the great advantage of being a branch of a most distinguished Institution of wide world reputation, and that without paying any extra subscription. I hope that we will add to the life and work of that Institution, and thereby promote both our own interests and the welfare of mankind. Papers and discussions here will be taken as delivered to the Institution of Electrical Engineers, and, if of sufficient merit, will be published in its Proceedings, thus securing to us a wide world publication, while at the same time ensuring that Ireland is credited with the work done. Why, for example, should the long-expected account of the pioneer electric railway at the Giant's Causeway be sent to London to be read and discussed: it can now come here, to Ireland, where the work was done, we can discuss its

lessons, and if we perform our duties well the account of this great Irish work will be sent all over the world by our powerful parent Society.

It is one of the banes of scientific publication that there are so many different scientific publications. One must look here, there, and everywhere for what has been published. We are not going to add to this most serious and growing evil. By the patriotism of the parent Institution we need not start a local publication in order to secure credit for Irish work, done here, read here, discussed here. We can get all this credit and secure the advantage of local interest and at the same time avoid adding to a serious and growing evil. Thus this action of the Institution will be " . . . twice blessed, blessing him that gives and him that takes."

The history of electricity in the nineteenth century is far too large a subject for an occasion like the present one, but certain aspects of this history convey valuable lessons for the future and may well engage our attention in this the last year of the century and may help us to lay the foundations for further advance in the next. The aspect of the history of electricity during the nineteenth century to which I desire to direct your attention is as an object lesson of how to apply science to further the well-being of mankind. The history of any applied science might be considered in this aspect, but the history of applied electricity is particularly appropriate for being thus considered, for several reasons. The history is condensed within a few years, the discoveries of science have followed one another with extraordinary rapidity, and within a few years after the discoveries were made they have been applied to the use of man. It is just a hundred years since Volta discovered how to make continuous electric currents. Within a few years of that discovery their chemical actions were discovered and electric lights produced, both arc and incandescent. Twenty years afterwards the magnetic effect of an electric current was discovered by Œrsted, its mathematical theory evolved by Ampère, and the law of its intensity worked out by Ohm. Some fifteen years afterwards Faraday discovered how to produce electric currents by magnetism. Immediately after the discovery of the principle of the conservation of energy

it was applied to electro-magnetism, and the foundation of our whole system of electro-magnetic measurement was laid. Faraday's belief in the correlation of electricity and light, following lines suggested by Lord Kelvin, was forged into a consistent theory by Clerk Maxwell and this theory confirmed experimentally by Hertz. Such, in brief, is the scientific history of electro-magnetism during the expiring century, and on this science practically all the applications of electricity depend.

I may pause for an instant to consider where this theory now lands us. The all-pervading ether has been realised as the means of transmitting light, electricity and magnetism, and we are looking forward to its properties explaining chemical actions and gravitation. We are still looking for a theory of its structure which will give a dynamical explanation of its properties. We know how to express these properties by quantities we call electric and magnetic force, whose laws we know, but whose laws we are, as yet, unable to explain by any structure working on dynamical principles. So far as we know, the properties of electric and magnetic force are explicable upon dynamical principles; so far there is no known necessity for seeking for adynamical properties in the ether; so far we may hope to explain electro-magnetism upon the dynamical principles of Newton's laws without invoking any other principles than those of force and inertia, as expounded in these laws. Until, however, a satisfactory theory of the nature of the ether has been actually invented, there will remain some doubt as to the adequacy of these fundamental dynamical laws to explain all its properties. The direction in which it is most probable that an explanation will be found is in the hypothesis that the ether is of the nature of a perfect liquid full of the most energetic motion. We know that a gas consists of separate molecules in intensely energetic irregular motion. I expect that the ether is a perfect liquid in intensely energetic irregular motion: much more rapid than that of any gas: with a rapidity of internal motion comparable with the speed of light: maybe with enough energy in each cubic centimeter to keep hundreds of horse-power going for a year, if only we could get at it. So far as this hypothesis has been worked at there seems nothing impossible about it, but, on the contrary, much possibility

in it, and, to my mind, its inherent simplicity confers on it a great probability.

Be that as it may, we now know that in the electric lighting of our cities, in electric tramways and railways, in electric furnaces and electrolytic vats, and in the other innumerable applications of electricity, we are harnessing the all-pervading ether to the chariot of human progress and using the thunderbolt of Jove to advance the material welfare of mankind.

Having thus shortly considered the progress of electrical science, the history of the *applications* of electricity may be thus summarised. Shortly after Œrsted discovered the magnetic effect of an electric current this discovery was applied to telegraphy, and Faraday's discovery of how to generate electric currents by magnetism was almost immediately applied to the same use. Telegraphy developed rapidly, and many subsequent discoveries were due to the observations made in the practical application of electricity to telegraphy. This has been developing ever since, accumulating knowledge and applying the accumulations to produce more knowledge and more applications, till all this has resulted in the perfection of the multiplex telegraph and the wonders of the telephone and wireless telegraphy. No other department of applied electricity has had such a continuous development, hardly any interval elapsing between discovery and application in its case, while in almost every other case years have elapsed between discoveries and their application. It is especially the object of this address to call attention to the cause of this and to the lessons to be learnt from it.

Within the first decade of the century electrolysis and the electric light were discovered, but, except on a small scale in electro-plating, it was reserved for the last quarter of the century to see their application to the general use of mankind. Before her Majesty began to reign, Faraday had discovered how to generate electric currents by magnetic actions; but, except to generate currents to light a couple of lighthouses, no applications of Faraday's discovery to generate electric currents on a large scale was made till Wilde, Gramme, and Siemens worked at it, more than thirty years after its discovery. The application of electric currents to transmit power on a small scale was made in

the electric telegraph years before any applications were made on a large scale. Except for a few experiments by Jacobi and others, the transmission of power by electric currents on a large scale is the work of the last twenty—one might almost say of the last ten years.

Consider now what are the characteristics of the applications which developed continuously, and what were those of the applications which lay dormant for years. Maybe we can learn from this consideration how to arrange that, in the future, our discoveries may not lie for years dormant.

The most noticeable difference between the applications of electricity that developed and those that lay dormant is that those that developed were useful on a small scale, while those that lay dormant were not useful until developed on a large scale. Electro-plating and telegraphy were useful on quite a small scale. Experiments as to their efficiency could be conducted on the laboratory scale with quite cheap apparatus, and thus they were actually developed.

A recognised authority, who is fond of poking paradoxical fun at Professors, has recently stated that "the progress of telegraphy and telephony owes nothing to the abstract scientific man." I do not know exactly what he means by the abstract scientific man, but I do know that telegraphy owes a great deal to Euclid and other pure geometers, to the Greek and Arabian mathematicians who invented our scale of numeration and algebra, to Galileo and Newton who founded dynamics, to Newton and Leibnitz who invented the calculus, to Volta who discovered the galvanic cell, to Œrsted who discovered the magnetic action of currents, to Ampère who found out the laws of their action, to Ohm who discovered the law of the resistance of wires, to Wheatstone, to Faraday, to Lord Kelvin, to Clerk Maxwell, to Hertz. Without the discoveries, inventions and theories of these abstract scientific men telegraphy as it now is would be impossible. Maybe the paradoxer means by an abstract scientific man one whose work has not yet been used in telegraphy: in that case the statement is true, but then it is a platitude. Perhaps he does not consider that the work of these men conduced to the *progress* of telegraphy; but then he should maintain that Œrsted's discovery of the magnetic action of an

electric current was no advance on the previous method of telegraphy by irritating snails. I daresay he modifies Sam Weller's idea and considers that algebra, geometry, mechanics, sound, heat, light, electro-magnetism, chemistry, come by nature, but that we must learn the "Morse code."

He goes on, however, to say that "the fundamental principles and natural facts that underlie the practice of electrical engineering are the teachings of actual experience, and not the results of laboratory research or professorial teaching." I pass over the implication that laboratory research is not actual experience and that professorial teaching is not founded on actual experience. I see that he must be in great difficulties in drawing the distinction he implies between experience in and out of laboratories. The difficulty he is in is quite natural, because there is no such difference. It seems to me impossible to understand how anybody who has not a bee in his bonnet and who knows anything of the history of telegraphy can make the extraordinary statement I have quoted. One would have imagined, apart from this authoritative statement, that "the fundamental principles and natural facts" underlying the practice of electrical engineering were the pile of Volta, the electrolysis of Davy and Faraday, the magnetic force of Œrsted, the laws of Ampère, Faraday's magnetic induction, the conservation of energy of Joule and Helmholtz, Kelvin's theory of cables, Ewing's hysteresis, Clerk Maxwell's theory of electro-magnetism, Hertz's electro-magnetic waves, Branly's coherer. Every one of these is essential to some part of modern electrical engineering, and every one of them was the result of mere "laboratory research" and "professorial teaching." The quoted statement is one of the most absurd paradoxes ever propounded.

I am delighted, however, to see that Sir William Preece emphatically states that "the engineer must be a scientific man." That really concedes all that has ever been in dispute between scientific men and engineers. Of course no "laboratory research or professorial teaching" can teach all that an engineer should know. How to deal with a drunken workman, or a strike, or a city corporation, or a board of directors, these, for example, have not yet been reduced to such scientific principles that they can

be made the subjects of profitable "laboratory research or professorial teaching." These and many other things can only be learnt by experience outside schools and universities, and it is one of the important problems of education to decide where school education should end and apprenticeship begin. I would, however, appeal to all engineers not to expect pupils coming from schools to have been taught to be immediately useful. No doubt this would save their employer a lot of trouble, but it would prove that the school had wasted the time of its pupils in teaching them what they should learn in the office.

We have, then, seen that electro-plating and telegraphy were capable of development on a small scale and were consequently largely developed by laboratory research.

The development of dynamos from Faraday's discovery required expensive experiments, and to test their efficiency on a large scale required very expensive experiments indeed. It was not possible to conduct experiments, that would be of much practical use, on the small scale on which laboratory experiments have to be conducted on account of the miserable pittance that is at the command of scientific laboratories. The only opportunity of conducting experiments on a large scale is when an inventor can control capital, as, for example, if he is himself in the position of an engineer to some wealthy body whose money he can employ on experiments. Jacobi and others spent a good deal of money, no doubt, on experiments in power distribution by electro-magnetic engines, but their expenditure, though quite considerable as compared with the usual run of laboratory experiments, was as nothing compared with the enormous sums spent by the pioneers of modern electro-magnetic machinery on *their* experiments.

What we have found, then, is that development depended on whether or no people experimented energetically upon how to render each discovery of practical utility; where experimenting was energetic, development was rapid; where experimenting was not energetic, development was slow. We have further found that the energy of experimenting depended on the money available; where little money was required development was rapid, but it was slow where large sums of money were required in order to perform *valuable* experiments.

We may further inquire how it happened that money and time became available for costly experiments. Money is available for laboratory experiments by the beneficence of private and public endowment, and time is available by the devotion of scientific men to the advancement of natural knowledge. These have been available because some few men have had faith in the desirability of knowledge both for its own sake and for the material and moral advantage of mankind. Money has been available in England on a large scale in the past because of the enthusiastic faith of some very few men in the possibilities of scientific discoveries. One of the most remarkable instances of this faith was in the case of the great experiment of laying the Atlantic cable. A few men with strong faith impressed their belief on a few capitalists, and after years of most expensive experimental work they at last brought their great undertaking to a successful issue; the general body of capitalists meanwhile looking on with amused incredulity. The development of the dynamo depended similarly upon the strong faith of individuals who spent immense sums of money and much time and energy on the subject because they had faith in its possibilities. It is remarkable how many of the developments of scientific discoveries of the latter years of the century have been due to foreigners or firms with foreign leaders, such as Siemens Brothers. This has been largely due to the fact that foreigners are far in advance of us over here in their faith in the possibility of using scientific discoveries. The rapid advance of the applications of science in the last quarter of this century has been very largely due to the growth of this faith. It has grown to a strong conviction in the ordinary public of America and the Continent, and is growing daily stronger over here, but is still far weaker here than in other parts of the civilised world. The result of this has been that while the germs of many of the greatest inventions have been made within the British Isles, we have not been pioneers in any great advance in the applications of electricity since the development of submarine telegraphy. Possibly another cause has been our obstinate retention of our abominable series—one cannot call it system—of weights and measures. It is with great hopefulness that I see public opinion gradually growing in favour of the metric system. It is

lamentable how the uninstructed prejudice of the man in the street influences progress. Here is a reform advocated by a large number of manufacturers and distributors, by chambers of commerce, and by almost everybody who has seriously studied the question, and yet it is delayed, not because the leaders of the State have any doubt as to its desirability, but merely because they do not think the public sufficiently intelligent for its introduction to be popular. Thus do we all suffer for the sins and ignorances of one another. It is a matter in which we in Ireland are particularly interested. I feel sure that under Continental guidance Ireland would long ago have adopted the reform, only that the obstinate conservatism of Britain has forced us to use its horrible series of weights and measures. If only our Irish members would push forward this reform they would do some good by saving a year's school life for each child and facilitating computations in every department of life; it would be worth much more than the millions they say Britain is robbing us of. Owing to these amongst other things we have not been pioneers. No doubt there are some advantages in not being pioneers; we are saved the expense of preliminary experiments, and can often enjoy learning by the mistakes of others. On the other hand, we lose such industries as electric tramway construction and polyphase transmission of power, and can never expect to be in the forefront of progress; a decided misfortune when it comes to fighting against Creusot guns.

How does it happen that one of the foremost countries in advancing science has been one of the last to appreciate the possibilities of applied science? This has been due partly, no doubt, to our great success as manufacturers and as mere mechanical inventors. No doubt Watt was a truly scientific inventor, and even mere mechanical inventors are appliers of scientific knowledge that was discovered, in the most part, by scientific men centuries ago; but most of our success as manufacturers has been due to mechanical inventions and to our well-trained and expert artisans, and not to the useful application of recent scientific discoveries. This great success, and the absence of scientific training in our schools and the want of contact between manufacturing and scientific society have all contributed to prevent a due appreciation of the value of scientific discovery and experi-

ment as a means of advancing the material wealth of society. The very word "science" has contributed to the mistake. As has been recently pointed out to me by Dr. Trouton, it would be impossible to say the same contemptuous things of "knowledge" as are said of "science." In Germany the word used, "Wissenschaft," is the one corresponding to our word "knowledge," and there nobody of any sense could say that "knowledge is all humbug," as is here often said, and still oftener thought, of "science."

How otherwise can one explain an eminent authority's recent paradox: "Many people advocate the early teaching of science; I do not," and then he immediately goes on to advocate the early teaching of botany, zoology, and physiography. He seems to use the word "science" for what he calls "ill-digested text-book science, illustrated by experiments which generally fail." I don't suppose anybody advocates the teaching of this "science" even late in a boy's education. I am afraid he is trying to earn a cheap popularity with the uninstructed "laudator temporis acti" by sneering at the early teaching of science and by an absurd misuse of the term that would not have misled his most ignorant hearer if he had used the word "knowledge."

We are, however, I confidently believe, already entered upon a more reasonable era. In England, even wireless telegraphy, the child of one of the most recent discoveries of science, has received sufficient recognition for very expensive experiments to be carried out with most valuable results, notwithstanding the cold shoulder given to the invention by Government departments and the fear it has inspired that it may be in the hands of the company promotor. Its history is most interesting as showing how much in an invention depends on the push and energy as well as upon the ingenuity of an inventor. In this connection I would strongly endorse the complaint of the President of the Institution of Electrical Engineers in his opening address, namely, that capitalists are unwilling to advance money to try experiments on a sufficiently large scale to be of service in deciding their value on a very large scale. A company can be promoted with a capital of £100,000 for almost any conceivable object, but it is quite hard to get £10,000 or £20,000 to try experiments. I look forward to the time when eager capitalists and energetic Government

departments will importune inventors to be allowed to work out their discoveries, instead of requiring to be solicited and ballyragged by the inventor into an unwilling permission to try them. A few failures now and then, a few cases of being taken in by fraudulent or over-zealous inventors, and our wavering faith in science collapses. How many failures are there in the iron trade! how many are taken in by specious company promoters! And yet the capitalist has faith in the "iron business" and in "limited liability companies." Would that our faith in science were equally strong! We might then hope that laboratories would be reasonably endowed with men and means to carry out experiments on a sufficient scale to be of use in testing their practicability and improving the methods of new inventions. I am delighted to see that Sir William Preece expects laboratories to carry on all the researches engineers may require. That is quite as it should be, but such laboratories must be very highly endowed. A physical laboratory that spends a couple of hundred a year on materials, instruments, and so forth, considers itself fairly well off. I wish I had anything approaching this to spend in Trinity College, Dublin. When will poor T.C.D. get credit for wanting to do more, very much more, than its very limited and precarious income permits? When can we expect the country or generous benefactors to learn that science on a large scale is at the basis of the material prosperity of the country, and that science on a large scale is very expensive. But what use is £200 a year in making experiments on a commercial scale? Ten thousand a year would be more like the figure required; and £10,000 a year could be most profitably spent on experimental work here in Ireland, on the one subject of utilising our bogs. It is most probable that the energy of their combustion could be transmitted to our towns to provide them with light and power; but the preliminary experiments are far beyond the capabilities of a scientific laboratory, and though success is very probable, it cannot be so certainly promised as to justify one in enlisting the assistance of capitalists who would consider themselves very badly treated if failure was ultimately discovered to be inevitable. If the capitalists were decently educated and could themselves appreciate the scientific situation, it might be allowable to enlist their

assistance as they might be considered to be going into a speculation with their eyes open. In the present state of the education of capitalists in this country they must depend entirely on the judgment of scientific experts, who cannot be expected to fully appreciate the business side of the subject. Then there are the questions of three-wire tramways, leaky telegraph lines, submarine relays, sun engines, of flying machines which Lord Rayleigh considers can be constructed if money enough were forthcoming, and of vacuum tubes as a means of illumination, and of numberless other matters already ripe for application, to say nothing of the innumerable scientific discoveries that have not yet been even suggested as having practical applications.

Besides these industrial laboratories, all our Government departments, such as the army and navy, should have large experimental organisations where any invention that promised success would be developed and seriously tried. The decision of what to try should not be left to mere officials, however distinguished, but should be referred to independent scientific advisers—persons who were not trammelled by official traditions, but were in touch with scientific advance and enthusiastic believers in it. If the country spent a couple of millions per annum on experimental work of this kind it would bear much fruit, and we should not find ourselves out-shot by semi-barbarous farmers.

Hope is the great incentive to exertion. Without it a nation is dead. Without it we lose all belief in the possibility of improvement, and improvement at once becomes impossible. The history of electrical engineering, the utilisation of the all-pervading ether for the service of man, should strengthen our hope and our belief in the possibility of improvement. For has it not revolutionised society and enabled high and low, rich and poor, to lead better lives, by making life less hard and grimy, and thus improved the well-being of man both materially and, what is far more important, morally as well?

Colonel C. F. C. Beresford, in proposing a vote of thanks to Professor Fitzgerald, said he felt sure that the future of this Section would be so prosperous that, in days to come, they would look back upon the first meeting this evening as an historical event closely associated with the name of the first chairman of the section, Professor Fitzgerald. Colonel Beresford.

He recalled the *story of the* examiner who, having received from a

Colonel Beresford.

candidate in reply to his question, "What is electricity?" the answer "I did know, but I have forgotten," remarked, "How very unfortunate that the only man who ever knew what electricity is has forgotten!" He would not prophesy that the meetings of the section would result in the discovery of what electricity is, but it would be safe to assume that the discussions would contribute to the making of further discoveries as to the laws which govern its action, and enable man to bind it to his service.

He remarked how at the present time all thoughts naturally turned towards the art of war, and in no direction was there a wider scope for the advance of electrical science. On it depended the efficiency of submarine defences, and coast batteries were directed and worked by its aid. The electric light had many uses in war, the latest development being the use of the search-light for signalling by means of its reflections in the clouds, thus enabling a beleaguered garrison to communicate with the relieving army. Then there were the field telegraphs and the Marconi apparatus, which latter was being used in war for the first time, and was likely to prove of inestimable value; for by its use it might be possible in future campaigns to dispense with long trains of telegraph material, and the necessity for erecting, maintaining, and guarding lines of telegraph. The mention of these instances of the application of electricity for war purposes showed that there was a wide field for its future study and discussion in the military as well as in the civil world—and at that very time the parent Society was sending out a detachment of Volunteer Royal Engineers to take part in war in South Africa. It was understood that Major Crompton was going out himself in command, and was taking with him a "galloping search-light." This would be a new departure in war, and one which would have astonished our forefathers very considerably, though there is little doubt that Napoleon would have made an excellent use of it, had it been invented in his day. It may well be imagined that a number of rapidly moving search-lights might be used with great tactical effect during a night attack, to show up the objective and to dazzle the enemy.

Professor Fitzgerald in his address had lamented that Great Britain was not a pioneer in the useful application of electrical science. This was doubtless true, but at the same time it must not be forgotten that war telegraphs were an exception. They were first used by the British forces in the Crimea, and since that date the British nation might flatter itself that they have been kept in advance of the field telegraphs of Continental armies.

Dr. Traill.

Dr. A. TRAILL said he had much pleasure in seconding the vote of thanks to Professor Fitzgerald for his instructive and suggestive address. Having been called on to make impromptu remarks, he could not go into all the matters touched upon, but would confine himself to the difficulty pointed out by the President of combining the possession of capital with the ability so to use it as to make the application of abstract principles commercially successful. Generally speaking, in England capitalists could be found who would back up the experiments of scientific men in whose ability they had confidence, but such a phenomenon was rare indeed in Ireland. Professor Aryton once told

him that there are often persons in England, not of much scientific ability, who think they have hit off some wonderful discovery, with which they are anxious to have their names associated, so as to become famous to posterity. They would come and say "there are £5,000 for you to experiment with, and bring my theories to a success in practice." Was it not a pity that such capitalists did not come and offer their money to carry out experiments evolved from their inner consciousness by such skilled persons as Professor Fitzgerald, and drop their own absurd ideas? On the other hand, reference might be made to two remarkable examples of men beginning without any capital, and by the extraordinary power of their intellects so impressing the public with confidence in their experiments as to succeed in amassing large wealth for themselves in the end. The first example was Sir William Siemens, —who, in an address to a Mechanics' Institute at Birmingham, many years ago, related how he and his brother, Werner Siemens, arrived, as young men, in London from Germany, having discovered the art of electro-plating. They could scarcely speak a word of English and were looking about everywhere for the Patent Office, where they might secure their discovery before making it known to the public. They had some £2 in their pockets. As they wandered through the streets they saw over a door in large letters, "Poole, undertaker." They felt certain that they had discovered the right place; they went in and commenced, in broken English, explaining their discovery, and asking to have it patented. The head of the place listened to them in confusion and amazement, and it was some time before he was able to make them understand that they had come prematurely to his establishment. When, however, he had discovered the object of their visit, he sent them on to Elkington in Birmingham, who had himself made the the same discovery that year, but in a very indifferent degree, and when the brothers told him that they could spread the small amount of silver in a fourpenny-piece over the entire surface of a large metal dish-cover, he offered them £1,000 for the discovery if they could do it. Of course they succeeded, and Sir William said that £1,000 was the first bit of capital they ever had. When we remember that he died leaving £380,000 in this country, of realised capital, besides a valuable business concern in England and another in Germany, it can easily be seen what splendid results were evolved from so small a beginning. He was a most remarkable man, and was one of the original Directors of the Portrush and Giant's Causeway Electric Railway. He had foretold the wonderful work which could be effected by the transmission of mechanical power from the Falls of Niagara by means of electricity, and it was well known what a stupendous success it had been within the few years which had elapsed since his great idea had been reduced to practice, under the guidance of a noble band of scientific men, amongst whom Lord Kelvin stood pre-eminent. The speaker and his brother had brought Sir William over to co. Antrim in 1880, and when he stood on the falls of the River Bush he clapped his hands and said, "Since I stood at the Falls of Niagara, I have not seen so suitable a spot as this on which to try the application of water-power to electric 'locomotion.'" That was the origin of the Portrush Electric Railway

Dr. Traill.

Dr. Traill. and Tramway, by many years the first in the world that was not a mere experimental toy. Unfortunately Sir William Siemens met an untimely end by a fall in the street in London, and there had been great financial difficulty in completing that line for some £45,000, as his firm not only refused to carry out his wishes and plans, but sent in a large bill for all the electric apparatus which had been used up in the many unsuccessful experiments carried out before ultimate success was attained. There was, however, another great man, Lord Kelvin, then Sir William Thomson, on the original Board of Directors, who furnished the speaker's second example of the creation of capital by the extraordinary commercial success of his discoveries in their practical application. Lord Kelvin was one of two remarkable brothers, but there had been this great difference between them—James Thomson, Professor of Engineering in Glasgow University, was a man of remarkable ability in his own profession, but he had never hit off the commercial aspect of great scientific discoveries, like his brother William. The great tribute paid to the eminence of Lord Kelvin three years ago, when his Jubilee was celebrated in Glasgow, is known to all. His discoveries had added more to human progress probably than those of any other man in the nineteenth century. Thousands of lives and millions' worth of property had been saved by his "mariners' compass" alone, and it was sufficient to mention the "Atlantic cable" to sum up all that the speaker was contending for. Rightly and deservedly, he had reaped a rich reward financially as well as scientifically, for his great discoveries. The history of the lives and work of these two great men proves conclusively that Professor Fitzgerald is perfectly correct in his criticisms on statements which have been made in comparing the man of abstraction with the man of action. In conclusion, he had only to add (though he said it in his presence), that Professor Fitzgerald was a man of the same stamp of mind as that of these two men. Lord Kelvin had himself told the speaker that he considered Professor Fitzgerald one of the first men of the day in that line of investigation to which he has devoted his life, and he only wished that he was a capitalist as well, as he knew that he would spend his wealth liberally in the great cause of science.

Professor Fitzgerald. Professor FITZGERALD said, in reply, that he was most anxious to do good to his own age and generation: that he would rather be of use to them than be known a thousand years hence as the discoverer of something which had remained useless for a thousand years. He did not at all despise money, as he considered it a generally fair measure of the usefulness of work. He concluded by thanking them for the way in which they had received his address, and hoped the branch would have a brilliant career of usefulness.

ORIGINAL COMMUNICATIONS.

A TWO-PHASE ROTARY CONVERTER AND A NOTE ON THE REGULATION OF ROTARY CONVERTERS.

By ERNEST WILSON, Member.

(*Paper received January 9, 1900.*)

IN a previous communication[1] experiments were described in connection with a Dynamo Electric Machine run as a single- and two-phase Rotary Converter. One object of the present communication is to examine more closely the armature reaction in the same machine when used to transform from two-phase alternate currents to direct currents. Other matters are also dealt with, and a note is given on the regulation of rotary converters.

In the previous experiments the two-phase alternate currents were supplied by two alternate-current machines, their axles being rigidly coupled together with the armatures 90° apart in phase. In the present experiments the two-phase currents are supplied by a machine similar to the rotary converter.[2] The armatures are each fitted with four slip rings making contact with the commutator at 0°, 90°, 180°, and 270°. The characteristic curve for each of these machines is given in Fig. 1, and each machine is intended to deliver 80 amperes 140 volts at 880 revolutions per minute as a shunt wound generator.

DESCRIPTIVE MATTER.

Fig. 2 is a diagram of connections showing how the converter C was connected to the generator G. The load on the converter was adjusted by a non-inductive resistance R, which was accurately determined at the time of the test. B is a Weston voltmeter. E is a Kelvin balance. The resistances r_3 r_4 r_5 r_6 are non-inductive. Q is a Kelvin

[1] See *Journal Inst. Elec. Eng.*, 1899, vol. xxviii., p. 367.
[2] For full description of these machines see *Proc. Roy. Soc.*, vol. li., p. 49; also *Dynamo Machinery*, by Dr. J. Hopkinson; also *Electrician*, vol. xxvii., p. 609.

quadrant electrometer. I and D are revolving contact-makers fixed respectively to the axles of the converter and generator. They make contact once in a revolution between brushes 5, 6 and 11, 12. The brushes 5, 6 are rigidly fixed at one point of a revolution. The brushes 11, 12 are fixed to an ebonite holder capable of being moved to different positions round a circle divided into 60 equal parts. When turned in the direction of rotation, the pointer passes over the divisions in the order 60, 59, 58, etc. K is a condenser of 1 micro-

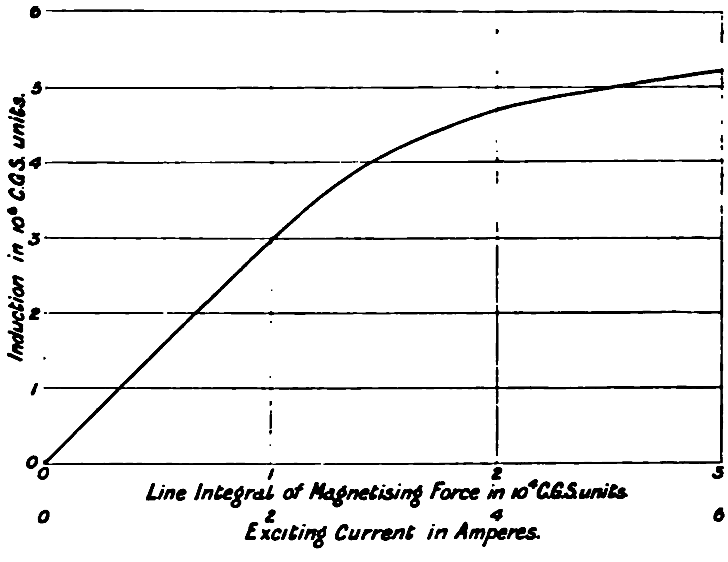

FIG. 1.

farad capacity. When observing the potential difference at any moment between the rings 1 and 3, the two-way switch S was set to connect the junction of r_1 r_2, two considerable non-inductive resistances, to one pole of the electrometer reversing-switch L. The contact-maker D was then set to different positions, and at each the double deflection observed. When observing the current in the brush connected to ring 1; the switch S was set to connect one pole of L to the terminal of r_5. The deflection of Q is proportional to the current at the moment when D severs contact between brushes 11, 12. Similarly the curve of current can be obtained b ving the variation of potential

difference across r_3. The other phase (rings 2 and 4) can be dealt with as just described by suitably changing the connections.

When observing the mechanical displacement between the armatures C and G at one part of a revolution, the contact-makers I and D were placed in series with one another and in the circuit of a battery and galvanometer. When the armatures of C and G were similarly placed with regard to the pole-pieces, and when the contact-makers I and D made simultaneous contact, the reading on D was 29. When in motion it was therefore only necessary to move the brushes 11, 12 to such a position that the contact-makers

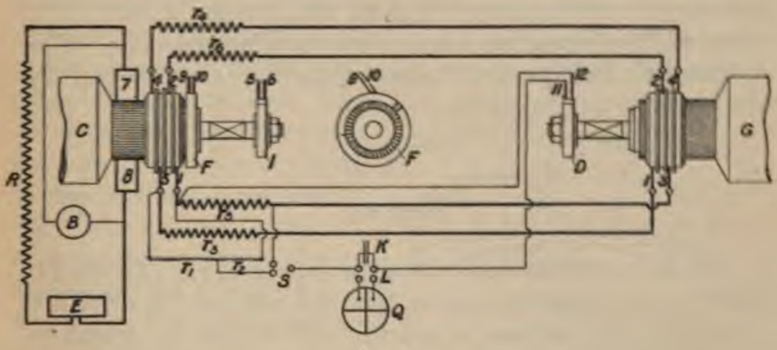

FIG. 2.

again made simultaneous contact to find the displacement required. If the angular velocity of each armature was constant, then by suitably placing the brushes on D, a steady deflection on the galvanometer would be observed, provided the periodic time of the needle is great. If, however, one armature is accelerated relatively to the other, the change is at once marked by the spot of light momentarily swinging back towards zero. A D'Arsonval galvanometer was used, and its damping was such that the rate at which simultaneous contact between I and D was made could be counted in certain cases.

EFFECT OF ENGINE AND BELT UPON ANGULAR VELOCITY.

For the purpose of these experiments it was desirable that the angular velocity of the converter armature should not vary. The generator was driven, to begin with, by a

leather belt with laced joint. The effect of this joint was very marked when the generator and converter were excited with weak fields—that is to say, the frequency with which the joint in the belt struck the pulley of the generator coincided with the beats of the D'Arsonval galvanometer above mentioned. The amplitude of the superposed oscillations was determined by moving D until the galvanometer just showed a deflection. The results of some of the tests are set forth in Table I., from which it will be seen that the amplitude with weak fields varied from 18° to 14° (that is 9° and 7° on each side of the mean) as the converter is loaded. With strong fields the beats of the galvanometer coincided with the revolutions of the crank shaft of the engine, which is compound, non-condensing, with two cranks at 90°. The effect of load is to give a more even turning moment. The leather link belt proved more satisfactory, as is shown by the experiments in Table I.

TORQUE.

We have now to deal with experiments 1, 2, 3 (Tables II. and III.), in which the leather link belt was used to drive the generator. To obtain a marked effect due to armature reaction weak fields were employed. To obtain as perfect symmetry as possible the total resistance of the conductors between the generator and converter were made equal, and can be considered free from capacity and self-induction so far as these experiments are concerned. The resistances r_3 r_4 r_5 r_6 (Fig. 2) have respectively the values ·0547, ·0553, ·0548, and ·0542 ohms. The first test for symmetry is to compare the curves of currents obtained by observing the variation of potential difference between the ends of r_3 and r_5 respectively in the circuits to rings 1 and 3; these should agree as regards amplitude, wave-form, and phase. Similarly with regard to r_4 and r_6 in the circuit to rings 2 and 4. In Figs. 4, 5, 6, the curves A_1, A_2 are each the average of the two curves obtained for each circuit, and the deviation of either curve from the average is so small as to be hardly detected in the diagrams. The curves V_1 and V_2 are the curves of potential difference between rings 1 and 3, and *rings* 2 and 4 respectiv ' V is the curve of potential

difference between the main brushes 7 and 8. The phase-differences between V_1, A_1 and V_2, A_2 are the same in one experiment, and the phases are 90° apart.

In the previous paper curves were obtained by observing the average potential difference between two small brushes touching adjacent segments of the converter commutator for different positions round the commutator. In the present experiments these small brushes, 9, 10 (Fig. 2), do not bear upon the commutator itself, but upon an insulating ring F, provided with two contacts only, such contacts bearing upon two adjacent commutator plates. By turning this ring on the commutator, the contacts can be made to touch any two adjacent commutator plates. For each setting of this ring on the commutator a curve was obtained by observing the deflection on a Kelvin Quadrant Electrometer connected to the brushes 9, 10 for different positions round the commutator. This curve gives, after correction for current into the resistance of the sections, a measure of the intensity of induction experienced by the particular section on the armature as it revolves. The sections have been numbered with regard to the commutator plate connected to ring 1 on the converter. The direction of rotation and the relative positions of ring 1 and sections 0, 1, 2, 3, etc., are shown in Fig. 3. In each experiment a curve, the points of which are taken every 10°, was observed for sections 0, 3, 6, 10, 13, 16, 19, 23. Three complete experiments, 1, 2, 3, are being dealt with in this section of the paper, and the observed curves are shown respectively in Figs. 7, 8, 9. The curves are numbered 0, 3, 6, 10, 13, 16, 19, 23, corresponding to the particular sections.

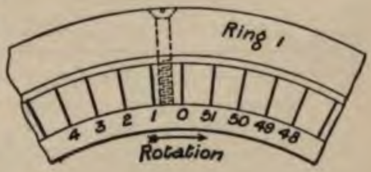

FIG. 3.

In each experiment a set of deduced curves has been obtained from the above, showing at a chosen moment the variation of potential difference between adjacent segments round the commutator. These curves have been corrected for the potential difference due to current into resistance of the different sections, and, on the assumption of constant angular velocity, give a measure of the intensity of induction at different points at the moment considered. The

correction to be applied is shown in Table III. The circle of reference is shown in Fig. 10 with regard to the pole-pieces, and the epochs chosen for these deduced curves are when section 0, and radial connection to ring 1, are at 120°, 141°, 162°, 189°, 210°, 231°, 251°, 279°. The results for experiments 1, 2, 3 are given respectively in Figs. 11, 12, 13, in each of which curve 120 means that section 0 is at 120° (Fig. 10) at the moment considered, and so on for 141, 162, etc.

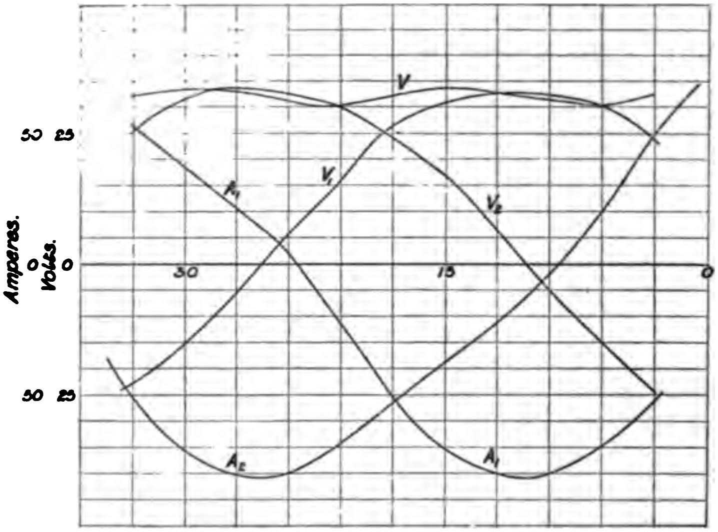

FIG. 4.

It is now necessary to find the currents in the converter armature at the moments when section 0 is at 120°, 141°, 162°, etc. For any position of the converter armature we require the position of the contact-maker between brushes 11 and 12, in order to find the actual values of A_1, A_2 and V at that moment. From V, the amperes A in the external circuit can be found, since $A = V/R$; R being a manganin strip which with leads has resistance ·474 ohms in each experiment 1, 2, 3. If the armatures C and G were exactly in phase mechanically, the generator contact-maker would read 59 when the brushes 11, 12 make contact, and when section 0, and radial connection to ring 1 of the converter, are at 90°

(Fig. 10). In each experiment the mean mechanical phase-difference is known, and the converter lags, so that the

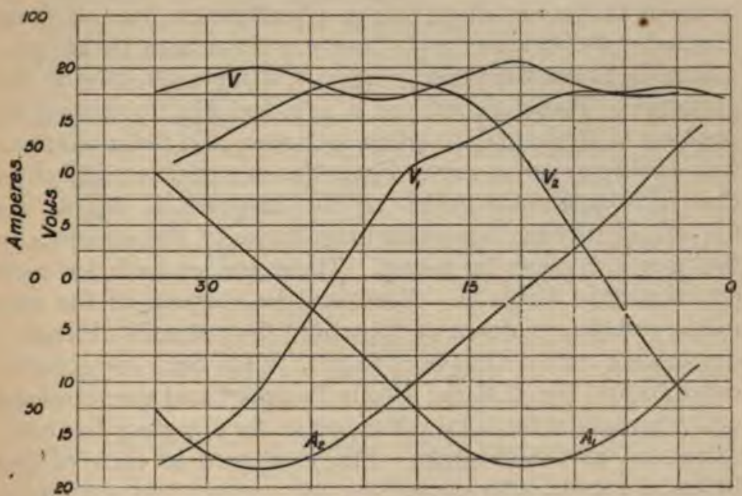

FIG. 5.

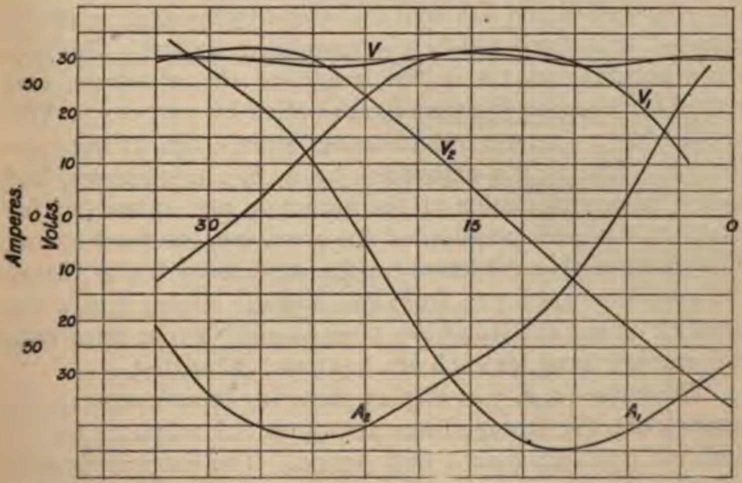

FIG. 6.

reading on the generator contact-maker scale for any position of the converter armature in each experiment is known. The values of A_1, A_2 and V have been found from the curves at the moments when section o, and connector to

ring 1, are at 120°, 141°, 162°, etc., and these are tabulated in Table II.

In this two-phase converter there are four radial connections to the slip rings 1, 2, 3, 4, and unless two of these are under the brushes 7, 8, there are three arcs to be considered between the main brushes 7, 8 on each side of the armature. These are lettered *a*, *b*, *c*, and Fig. 10 shows the position of the armature when section 0, and radial connection to ring 1, are at 120°. From the electrometer deflection the signs and magnitudes of the amperes A, A_1, A_2 are known, so that the signs and magnitudes of the currents in the arcs *a*, *b*, *c* can be found. These are set forth for each experiment in Table II. Knowing the currents in the arcs *a*, *b*, *c*, and the resistance of these arcs, the potential difference due to such currents has been found. V has been corrected in order to find the E.M.F. From the speed and convolutions of the armature, the total induction in the armature has been calculated in C.G.S. units. The total area of each of the deduced curves, after correction for current into resistance, in Figs. 11, 12, 13 has been found in square cms.; so that the value of an ordinate of 1 cm. is given in total C.G.S. units per 10°, by dividing the total induction by the area in square cms.—1 cm. horizontally corresponding to 10°. The area corresponding to 10° is the length of the armature, corrected for fringing (39·5 cms), multiplied by 1·73 cms. This enables us to find the induction per square cm. at the conductor. The angles embraced by *a*, *b*, *c* are known, and hence the average value of the induction per square cm. for each arc, for each position of the armature, has been found. The number of conductors on the surface of the armature embraced by 90° is 52; from this and the angles *a*, *b*, *c* the number of ampere-bars have been found. From these data the average force for each arc has been calculated.

The curves 1, 2, 3 in Fig. 14 show for experiments 1, 2, 3 respectively the average force acting on the armature for its different positions over a half period. The force has variations in each experiment, having a periodic time half that of the converter armature. Experiment 3 suffers greatest variation, and changes sign twice during the half period. The average forces over a half period in time, due to one half of the armature, given by the curves in Fig. 14, are 4·34, 5·18, and 4·62 lbs. in experiments 1, 2, 3 respectively.

[redacted]

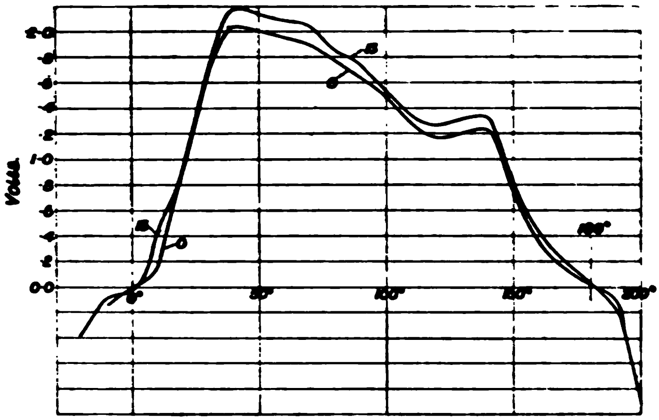

FIG. 7.

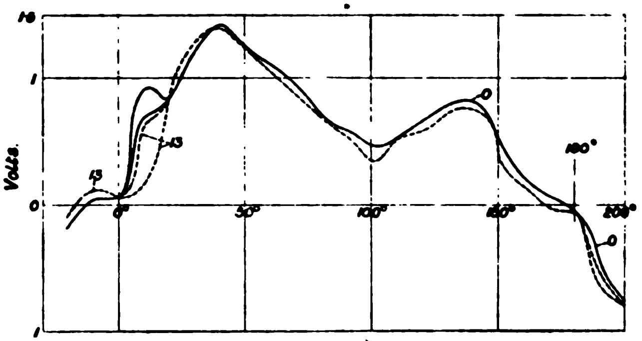

FIG. 8.

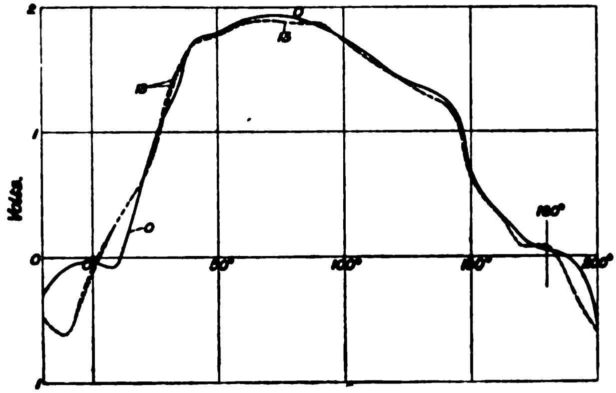

FIG. 9.

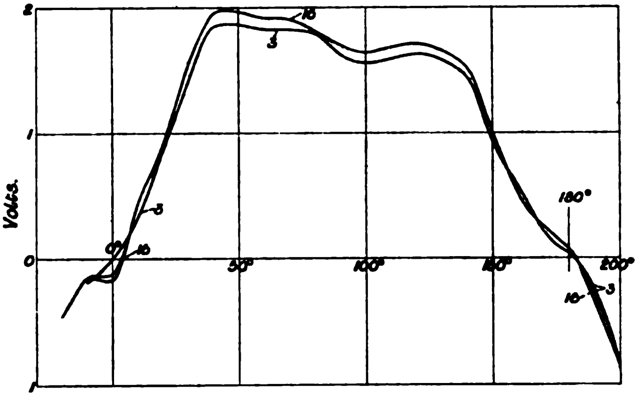

FIG. 7A.

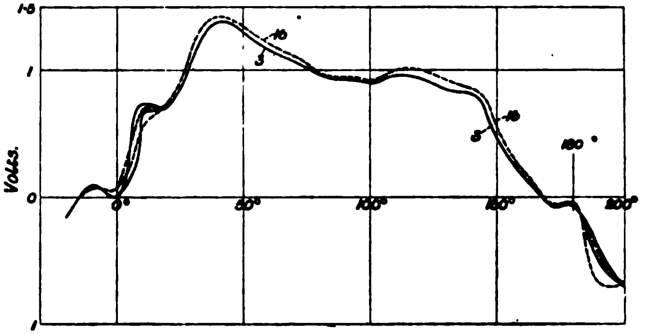

FIG. 8A.

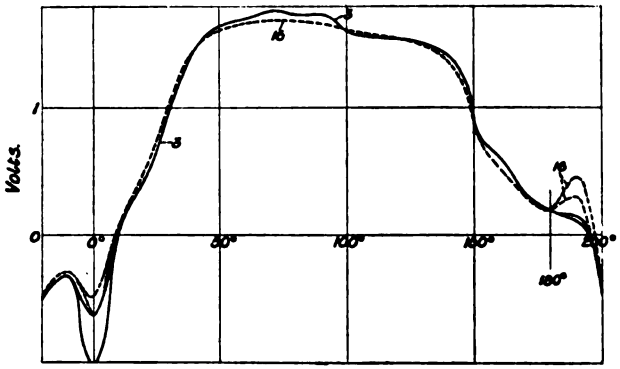

FIG. 9A.

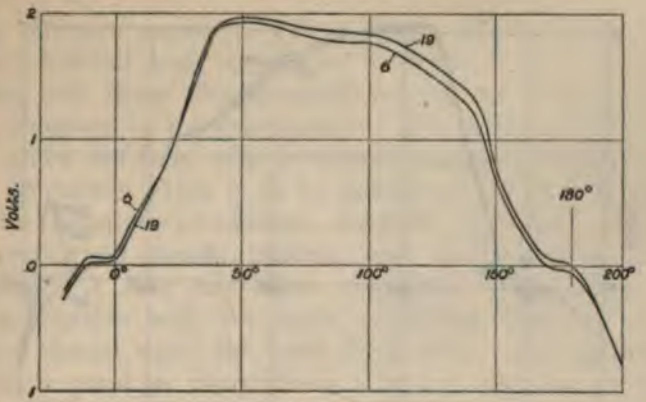

FIG. 7B.

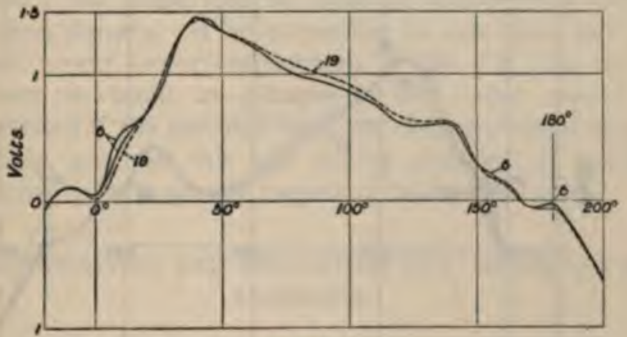

FIG 8B.

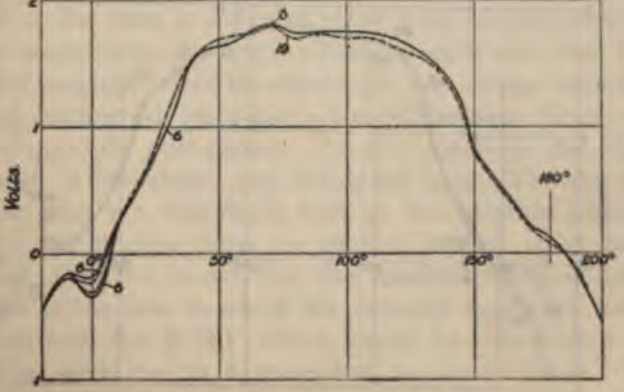

FIG. 9B.

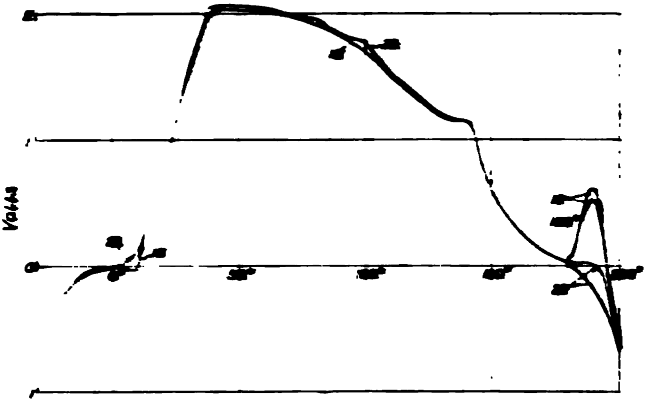

FIG. 7C.

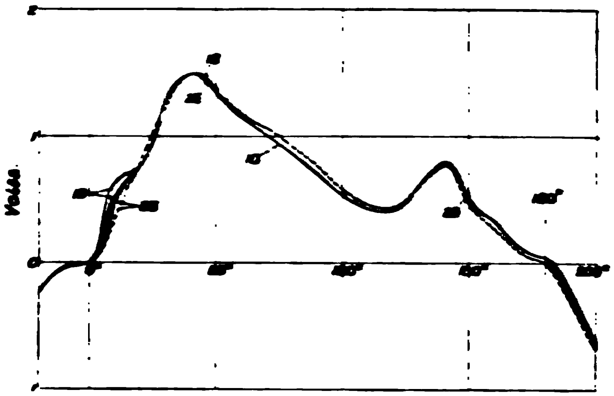

FIG. 8C.

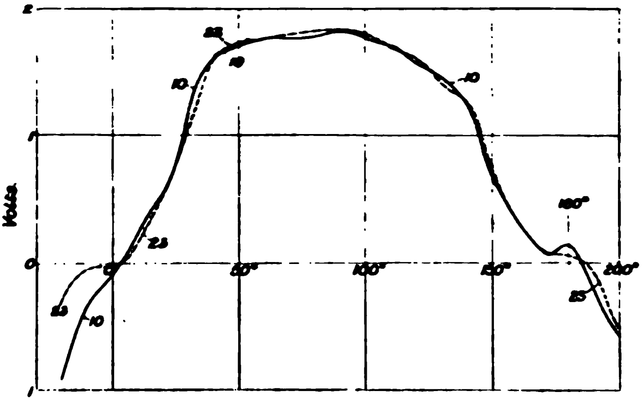

FIG. 9C.

The effective radius is 3·86 inches. These forces have been doubled and correspond to rates of 412, 437, 383 watts, and these should equal the powers taken to turn the armature in the experiments. Referring to Table III., we know the total rate at which energy is dissipated in the converter. This is to be accounted for by C^2R losses in the armature conductors, magnetic hysteresis, induced currents, and brush, bearing, and wind friction. The actual C^2R loss has been calculated from Table II. This, together with the watts calculated from the mean force, should equal the total dissipation. The agreement is fairly good in experiments 1 and 3, but not so good in experiment 2. In this experiment (No. 2) the variations of induction density are great, and to this the author attributes the large loss in spite of diminished average induction density. It is interesting to note that with the highest power factor (experiment 1) the C^2R loss in the armature is small as compared with what would be experienced if the machine were an ordinary direct-current generator, and that this loss can be exceeded by working the converter with greatly lagging or leading currents.

Magnetisation and Distortion due to Armature Currents.

In an ordinary direct-current dynamo, if the brushes 7,8 be fixed on the neutral line, the de-magnetising effect due to the current-bars on each side of the brush is zero. In a rotary converter the case is different, since with the main brushes on the neutral line the ampere-bars on each side may have different magnitude and the same sign. As an approximation we may confine our attention to the belt between the corners of the opposite pole-pieces. In this machine the angle embraced is 68° above and below the axis. The currents in these arcs are known as well as the number of bars, and the net ampere-turns are plotted in Fig. 15 in terms of time. Curve 1 shows that the resultant effect is small, and this is the case in which the currents A_1, A_2 are nearly in phase with the E.M.F. which would be observed if the converter were run as a generator on open circuit. The currents actually lag by a small angle (4·5°) and one would expect a small magnetising effect. The average ampere-

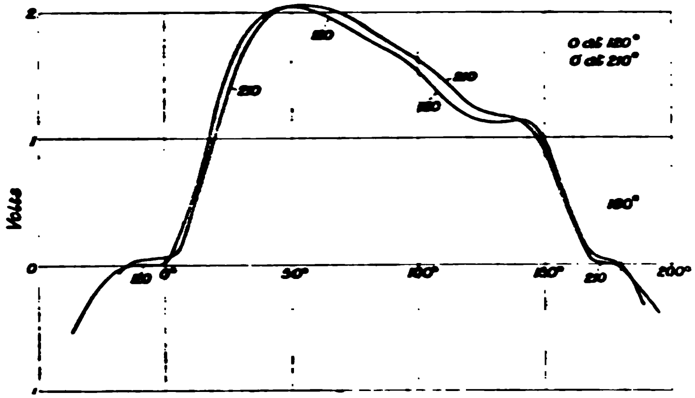

FIG. 11.

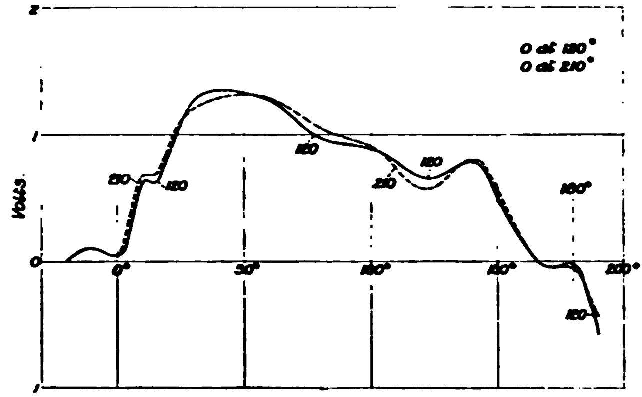

FIG. 12.

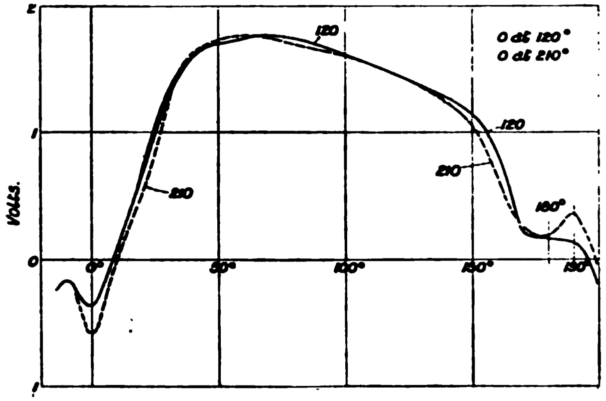

FIG. 13.

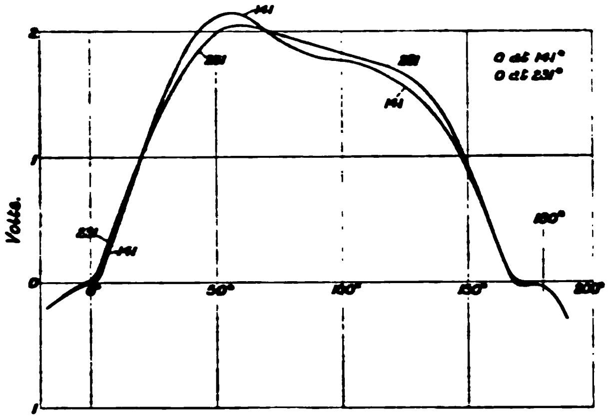

FIG. 11A.

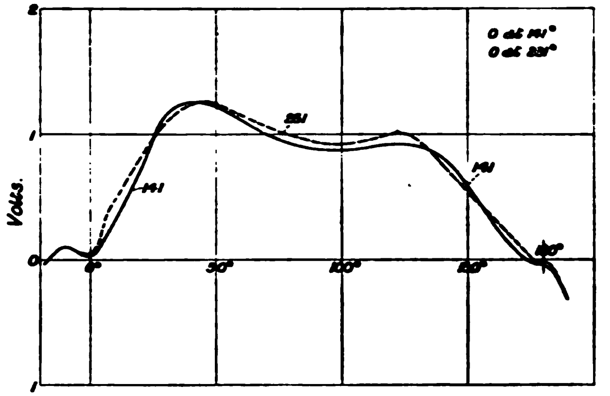

FIG. 12A.

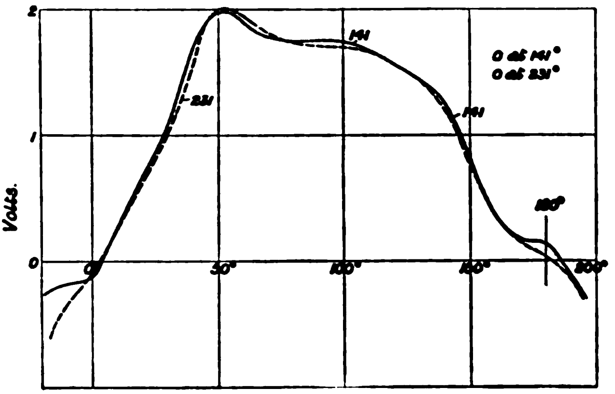

FIG. 13A.

observed potential differences V_1 V_2, have a bearing upon power factor. If the converter excitation be kept normally constant, we see that the volts V_1 V_2 only agree in phase with the E.M.F. as a generator on open circuit when the current lags, as in experiment 3, and then the mechanical phase difference is 6°. As the excitation of the generator is reduced the volts V_1 V_2, as well as amperes A_1 A_2, are accelerated in phase until current is nearly in phase with E.M.F. (Expt. 1), and the mechanical phase difference is 29°. In this case the power factor is not a maximum, since the amperes A_1 A_2 lag. On further reducing the excitation of the generator the amperes A_1 A_2 and volts V_1 V_2 come into phase, and after this the current overtakes potential difference and leads as in experiment 2, the mechanical phase difference being 63°. During reduction of generator exciting current the volts V_1 V_2 would be continuously reduced in amplitude, as well as accelerated in phase for constant speed and constant current on the direct-current side of the converter.—*March* 25, 1900.]

When observing the curves in Figs. 7, 8, 9, at certain points near the main brushes the electrometer deflection was unsteady. The limits of the variation are shown by the two lines under one curve number. The C.R. correction is important at these positions, and may, together with the acceleration, be connected with the effect observed.

When the connectors to rings 1 and 3, and 2 and 4 come under the main brushes, the potential differences observed between the rings and the main brushes respectively should be equal, provided the brush contact and leads have a small enough resistance. The following figures taken from the curves show that such resistances in this machine are not small as compared with the resistances of the leads and armature. The conditions may have changed between the observations, but the result is worth noting.

	Angle	V.	V_1	V_2	A_1	A_2	ohms.
Experiment 1	9·3	31·5	32·2		81		·0086
„ „	24·3	31·3		32·7		81	·0173
„ 2	3·6	17·5	18·0		44		·0114
„ „	18·6	17·25		18·75		43	·0350
„ 3	13·2	31·0	32·0		81		·0123
„ „	28·2	30·0		32·0		77	·0260

In the case of closed coil machines (mixed phases) the

subject of symmetry is of great importance. In some early experiments the resistance of the connecting leads were not accurately adjusted, as in the case of experiments 1, 2, 3. The dissymmetry was such that the phase-differences were as shown in experiments 4, 5, 6 (Table III.); the currents observed being taken across r_5 and r_6 only, and not the average as in experiments 1, 2, 3. Under these conditions, the disturbances in the air spaces of the converter were quite different for corresponding sections 90° apart.

The converter is here working intermediate between single and two-phase, and the average force worked out as in experiments 1, 2, and 3, on the assumption that the currents in rings 1 and 3, and rings 2 and 4, are given by the variation of potential difference across r_5 r_6 respectively, show greater variation than is the case in experiments 1, 2, 3, but the periodic time is still half that of the converter armature.

In experiments 2 and 5 the converter is just on the point of falling out of step. Any further diminution of the generator exciting current would make it do so.

Conclusions from Experiments.

The experiments show the magnitude of disturbance which may be produced in the angular velocity of a rotary converter by a joint in the belt used to drive the generator of alternate currents. The result points to the importance of employing an even turning moment in connection with direct-coupled engines and generators.

The experiments on armature reaction in this two-phase rotary converter, demonstrate that currents in phase with E.M.F. which would be observed if the converter were run as a generator on open circuit, have little or no effect towards magnetising or de-magnetising the magnets, and that lagging and leading currents respectively magnetise and de-magnetise the magnets. The disturbance is a periodic function, the time of which is half that of the converter armature, and makes itself felt at the main brushes of the converter. The distorting effect, due to the currents in the armature, has also a periodic time half that of the armature.

The torque actually experienced by the armature for all phases of current has fluctuations of periodic time half

that of the armature. The experiments confirm the result obtained in the previous paper, namely, that the mechanical phase displacement of the armature is less with strong than with weak fields.

With greatly lagging or leading currents the dissipation of energy in the copper conductors of the converter armature may be greater than the dissipation which would occur in the same armature if used as a generator to give the same direct current.

Attention is called to the importance of symmetry in a system in which mixed phases are employed.

The results of the experiments in this and the previous

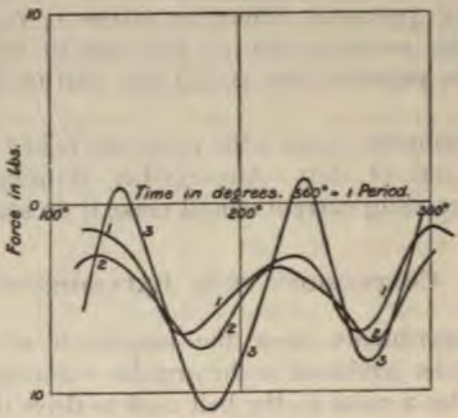

FIG. 14.

paper referred to are made use of in the following note on the regulation of rotary converters.

The Regulation of Rotary Converters.

The simplest case is that in which the exciting current in the magnet winding of the converter is supplied by an external source and kept normally constant, as in the foregoing experiments. If it be taken as a condition that the potential difference between any two points in the direct-current circuit of the converter must be kept constant for all loads, then the E.M.F. of the converter must be increased as the load increases. If a current in phase with E.M.F. as a generator on open circuit neither magnetises nor

de-magnetises, then for maximum power factor at the converter slip rings at all loads, the E.M.F. cannot be increased with constant exciting current in the magnet coil. In these circumstances the exciting current must be increased with the load. We may consider the following cases in which control is effected by the generator.

(1) Suppose with no load on converter that the field is

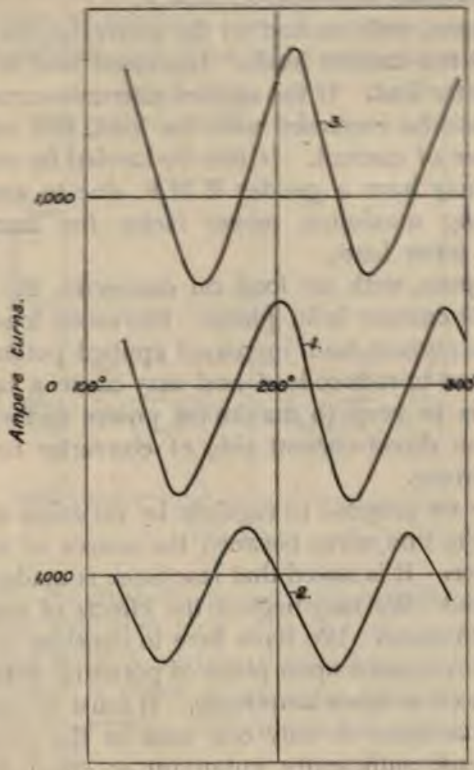

FIG. 15.

such as to produce a lagging current. Then loading the converter will reduce lag of current, and since a lagging current magnetises, the volts on the direct-current side will drop; if carried far enough a leading current and further de-magnetisation will result.

(2) Suppose, with no load on converter, the field is such that a lagging current exists, and that the applied alternate-current potential difference increases as the load increases.

So far as the applied alternate-current voltage is concerned the phase of current will tend to be increased. So far as load is concerned the phase of current will tend to be decreased. The actual effect on the phase of current will be that due to the resultant of an increased applied potential difference and an increased load. The result may be an increased amplitude of lagging current, magnetising sufficiently to produce the required E.M.F.

(3) Suppose, with no load on the converter, the excitation is such that the current leads. Increased load will tend to cause a greater lead. If the applied alternate-current potential difference be increased with the load, this will tend to reduce phase of current. If this be carried far enough, the converter may have a greater E.M.F. due to armature reaction giving maximum power factor for maximum or average or other load.

(4) Suppose, with no load on converter, the excitation be such that current is in phase. Increased load will tend to make the current lead, increased applied potential difference will tend to reduce lead and may cause a lag. If the net result is to keep to maximum power factor, the volts will drop on direct-current side of converter for constant exciting current.

Suppose we propose to regulate by variation of the conditions in the line wires between the source of energy and the converter. It is stated that reactance is made use of for this purpose.[1] We may neglect the effects of capacity and possible resonance. We have here to consider the effect of such added reactance upon phase of potential difference and current as well as upon amplitude. It must be remembered that such reactance is only one item in the circuit, and it must be made sufficiently important to effect the desired result. The following cases may be considered.

(*a*) Suppose, with no load on converter, the excitation is such that the current lags, and produces a magnetising effect. Let the reactance in the line wires be great, and by some automatic device let it be reduced as the load on the converter is increased. So far as reactance is concerned it will tend to diminish phase difference between current and potential difference, at the same time increasing applied

[1] *Journal Inst. Elec. Eng.*, 1898, vol. xxvii., No. 137, p. 724.

potential difference. So far as the converter is concerned, increased applied alternate-current potential difference and increased load act in opposite senses. The result might be an increased E.M.F. with a still lagging current of greater amplitude.

(β) Suppose, with no load on converter, the excitation is such that current leads. In this case, if the reactance be automatically increased as the load is increased there will be a tendency to decrease lead of current on the part of increased reactance, and the applied volts will be lower. In

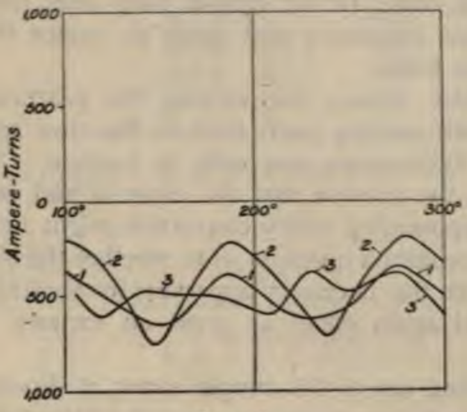

FIG. 16.

the converter, diminished applied potential difference and increased load will each tend to make current lead. The net result should be a current diminishing in lead as the load is increased in order to give the desired increase in E.M.F. of the converter. This might have to be carried so far that current lags.

It is usual to supply rotary converters with compound windings. Under these circumstances the field excitation increases with the load. An over-excited converter accelerates current, and the author presumes that the increased reactance is such that its tendency to cause a lag is such that the net result is a maximum power factor for the average or maximum load with sufficiently increased E.M.F.

(γ) Suppose the field such that with converter on open circuit current is in phase, and we vary reactance in such

wise that it automatically diminishes as the load on the converter is increased. A diminished reactance will tend to accelerate current, and the applied potential difference will be increased. So far as the converter is concerned, increasing its applied volts and load act in opposition. The net result should be a current slightly lagging in order to increase E.M.F. sufficiently to compensate for increased C R drop.

In a choking coil the tangent of the angle of lag between applied volts and current varies as L/R, where L is a supposed constant self-induction coefficient and R is the resistance of the coil. In the case of long lines, the resistance may become important and tends to reduce the angle of either lag or lead.

Automatic devices for varying the reactance if constructed with moving parts may be too slow to follow up the rapid fluctuations met with in traction. The author inclines to the opinion that the expense and complication due to compounding rotary converters might be done away with. It becomes a question as to whether the simple shunt winding with the necessary apparatus for varying the reactance would again entail as great an expense and be as efficient.

In making use of the simple shunt, it should be noted that with arrangements for increasing the potential difference, say between the brushes on the direct-current side of the converter, there is a means for automatically increasing the shunt current. This should be considered in the particular cases mentioned in this note, as it was there assumed constant. Again, the experiments show that the mechanical phase-difference is diminished with strong fields; this should be considered, as it has, in the author's opinion, an important bearing in connection with the hunting of converters. From this point of view, it would be best to work into a condition of stronger field as the load is increased if field variation is imperative; but if not, the field intensity should be high so as to reduce armature reaction.

Mr. F. E. L. Hurst, Student-Demonstrator in the Siemens Laboratory, King's College, London, has assisted me, not only in the experiments, but in the working out of results. Mr. R. D. T. Alexander has also given me assistance in the experiments. To these gentlemen I wish to tender my thanks.

TABLE I.

Magnetic Field of Converter and Generator.	Direct Current Volts. V	Direct Current Amperes. A	Watts.	Exciting Currents in Shunt Coils. Generator Amps.	Converter Amps.	Revs. per min. of Converter.	Mean mechanical phase difference between Generator and Converter.	Total variation of mechanical phase difference 360° = 1 period.	Remarks.
Weak	52·5	0	0	1·54	·81	905	3°	18°	Leather belt with joint. Beats of Galvanometer needle agree with frequency of joint in belt striking pulley.
	46	53	2440	,,	,,	890	18°	14°	
	25	29	727	·60	·82	900	57°	14°	
Strong	Brushes up	0	0	4·50	4·43	892	4·5°	14°	Leather belt with joint. Beats of Galvanometer needle agree with revolutions of engine crank shaft.
	145	0	0	4·45	4·37	887	5°	11·5°	
	137	40	5440	4·42	4·37	855	9°	11·5°	
Weak	Brushes up	0	0	1·5	·80	875	2°	9°	Leather link belt. Beats of Galvanometer needle difficult to count.
	52	0	0	1·5	·80	875	3°	,,	
	45	52	2350	,,	,,	863	16°	9°	
	24	27·9	670	·60	·83	873	60°	6°	
Strong	Brushes up	0	0	4·30	4·30	875	3°	9°	Leather link belt. Beats of Galvanometer needle difficult to count; almost a permanent deflection.
	135	39·5	5330	,,	,,	825	6°	7·5°	

THE AIR-GAP INDUCTION IN CONTINUOUS-CURRENT DYNAMOS.

By C. C. HAWKINS, M.A., Member, and R. WIGHTMAN, Associate.

Although the principles which govern the distribution of the magnetic induction in the air-gaps of the continuous-current dynamo are well known, yet there are certain points in the predetermination of the complete curve of induction under and beyond the pole-faces, which merit detailed consideration. The subject is of especial importance in connection with the question of commutation, since upon the predetermination of the fringe of lines which form the reversing field between the pole-edges must largely depend our forecast as to whether a particular machine will be free from sparking or otherwise.

I.

Since the actual field in the air-gaps of the dynamo is the resultant of the weakened symmetrical field (due to the magnet winding, as weakened by the back ampere-turns of the armature) and the cross field, the first step towards determining the distribution of the lines right round the armature must be to map out the weakened symmetrical field, and upon this the distorting effect of the cross ampere-turns must afterwards be superimposed. When, however, we come to the interpolar region, the problem must even at this early stage be simplified by limiting ourselves to one more or less general case out of the great variety of forms which it may take. The distribution of the lines between the pole-edges is affected by the configuration of the magnetic circuit in general, and by the shape of the pole-tips in particular; it further depends on the position and number of the exciting coils per magnetic circuit. *E.g.*, in a two-pole iron-clad dynamo having the yoke passing close on either side of the armature and excited by a single coil, the interpolar field will be very different from that of the same armature and pole-pieces with two exciting coils symmetrically placed and the yoke so far away that leakage into it from the armature may be neglected. Again, even in the ordinary over-type

single horseshoe, the interpolar field at the upper surface of the armature will be different from that at the lower surface. Some general case which will give results more or less accurate when applied to particular machines must be assumed, and in the expression "weakened symmetrical field" used above it is implied that the field-magnet system is perfectly symmetrical with regard to the armature, as, for instance, in a two-pole machine when the total excitation is divided between two equal coils placed above and below or one on each side of the armature. It is further assumed that the yoke is so far from the armature that its effect

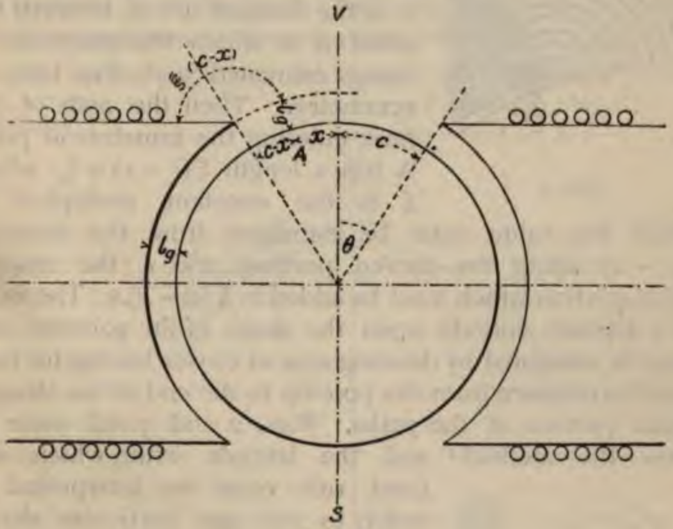

FIG. 1.

need not be considered (Fig. 1). Within the bore of the pole-pieces the lines in the interferric gap may be taken as radial and as uniform in density over some 85 per cent. of the polar arc.[1] For about $7\frac{1}{2}$ per cent. of the arc at each end of a pole-face the lines begin to curve outwards and their density diminishes. Beyond the pole-tip their path becomes more and more curved, and as a preliminary approximation it may be assumed that for all lines lying

[1] Thus in the curves reproduced in *Science Abstracts*, vol. i., part 9, while the pole-face extends over 135°, the density is practically uniform over some 110°; and in Dr. Hopkinson's curves (*Dynamo Machinery*, pp. 142 ff.) the straight-line portion which marks the limits of uniform density in the symmetrical field extends over about 100° out of a total polar angle of 112°.

between a pole-tip and the symmetrical diameter their path in the air may be divided into two portions—(1) a curved portion, the length of which is a constant multiple of the peripheral distance measured on the armature core from the line joining pole-tip and armature centre to the point at which the induction is to be estimated; and (2) the normal length of the single air-gap, l_g. Thus, in Fig. 1, let c = the distance in cm. measured on the periphery of the armature core from the vertical line of symmetry V S up to the radius drawn to the pole-tip. Let x = the distance in cm. between the point A at which the induction is being estimated and the line of symmetry. Then the path of the lines entering the armature at point A has a length $\xi(c-x)+l_g$, where ξ is the constant multiplier of which the value must be estimated from the drawing, $\xi(c-x)$ being the curved portion, and l_g the straight radial portion which must be added to $\xi(c-x)$.[1] The value of ξ depends entirely upon the shape of the pole-tips, and must be estimated by drawing arcs of circles having for their radii the distance from the pole-tip to the end of the straight radial portion of the paths. Figs. 2 and 3 will serve to show the method[2] and the latitude with which any fixed rule must be interpreted in order to suit any particular shape. If the pole-tips are not chamfered off so as to increase their radial distance from the core and their shape be simple, the following construction may be employed to determine ξ. If the circle of the bore be continued from the pole-tip up to the line of symmetry (Fig. 4), and any point A be taken on it, let γ be the angle in radians enclosed between the pole-edge B C and the chord from the pole-tip to the point A. Then the length

FIG. 2.

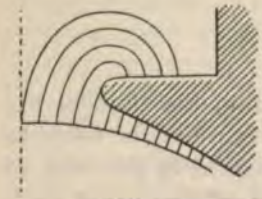

FIG. 3.

[1] The above convenient approximation is due to J. Fischer-Hinnen (*Elektrotechnische Zeitschrift*, 1893, vol. xiv., pp. 53–57), and is probably very fairly accurate near the line of symmetry, but, as will be seen later, requires modification near the pole-tips.

[2] *Cp.* Emil Dick in *E*... *he Zeitschrift*, 1898, vol. xix., pp. 802–806.

of the curved portion of the path is γ times the chord C A. For different points γ evidently alters slightly, and ξ is therefore not strictly constant; but if the point A′ midway between V S and C be taken as in Fig. 4, the value for ξ derived from the angle γ so obtained may with reasonable accuracy be assumed to hold for all other points, and may therefore be used as a constant multiplier. The arc C A being equal to the arc $(c - x)$ raised in the proportion $\frac{r + l_g}{r}$ where r is the radius of the armature, and γ in a two-pole dynamo with pole-tips as shown being approximately 120°, the chord C A′ works out to about 1·05 times the arc $(c - x)$ which is measured on the armature core, whence the curved portion of the path $= \gamma \times 1{\cdot}05\,(c - x)$, or $\xi = \frac{2}{3}\pi \times 1{\cdot}05$ = nearly 2·2.

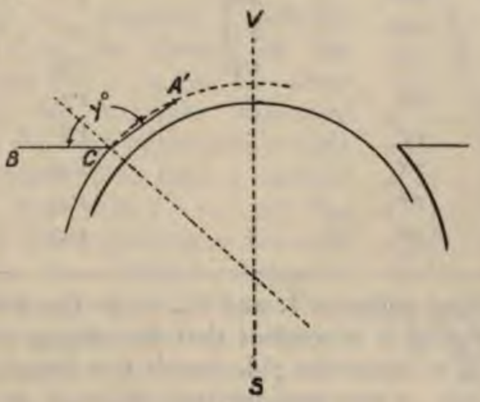

FIG. 4.

A numerical illustration will render the above clearer. Thus in an armature of 14″ = 35·6 cm. diameter, l_g was 1·42 cm. and $\xi = 2{\cdot}1$ as estimated from the drawing. The angle subtended by the pole-face was 140°, whence the distance on the core from a radius intercepting the pole-tip to the line of symmetry was $35{\cdot}6 \text{ cm.} \times \pi \times \frac{20^\circ}{360^\circ} = 6{\cdot}2$ cm. At the pole-edge, $x = c = 6{\cdot}2$ and $\xi(c - x) + l_g = l_g = 1{\cdot}42$, while on the line of symmetry $x = o$ and $\xi(c - x) + l_g = 2{\cdot}1\,(6{\cdot}2) + 1{\cdot}42 = 14{\cdot}42$; hence for every degree of advance away from the line of symmetry, $\frac{13}{20} = {\cdot}65$ cm. must be

deducted from the length 14·42. We thus obtain columns I. and II. of the following table :—

TABLE I.

I. Angle from line of symmetry = α.	II. $2{\cdot}1\,(c-x) + l_g$	III. Corrected.
0°	14·42	14·42
2°	13·12	13
4°	11·82	11·5
6°	10·52	10
8°	9·22	8·6
10°	7·92	7·17
12°	6·62	5·8
14°	5·32	4·2
16°	4·02	3
18°	2·72	2·4
20°	1·42	1·95
22°		1·7
24°		1·5
26°		1·44
28°		1·43
30°		1·42

On plotting columns I. and II., as in the dotted upper curve of Fig. 5, it is evident that the change as we pass from outside to inside the pole-face is too abrupt (since the curve consists of two straight lines meeting at an angle), and must in fact be more gradual. As has already been stated, the length of path of the lines towards the pole-corner is not absolutely radial, and only becomes so some 10° within the pole-face, *i.e.* about 7½ per cent. of the polar arc. Further, the curved portion of the path in reality becomes straighter as we approach the pole-tip, so that $\xi\,(c-x)$ should decrease more rapidly. It is therefore convenient to adopt some such conventional rule as the following: instead of making $\xi\,(c-x) + l_g$ decrease to l_g at the pole-edge, let the maximum value be diminished to zero at the pole-edge, and let the angle of intersection be rounded off between the limits of, say, 30° and 15°. This construction makes allowance for the decreasing value which ξ should have as the pole-tip is approached.

The full-line curve of Fig. 5 is thus obtained, from which the corrected values for the length of path given in the third column of Table I. are derived. As a matter of fact for the purpose of considering the reversing field, it is not so important to determine the field close up to the pole-tips, as the brushes are seldom advanced so far even at full load.

Next must be considered the difference of magnetic potential acting along the above paths. Let B_g = the normal induction over the polar arc (except at the extreme edges) at full load, so that $B_g \times 2\,l_g = 1{\cdot}257\ X_g$, where X_g = the ampere-turns required by the double air-gap. Let l_a = the distance in cm. from the radius intercepting a *N.* pole-tip to the radius intercepting an adjacent *S.* pole-tip measured along the outside of the armature core (*i.e.* $2c$ in Fig. 1). Over this length the armature induction (neglecting the lines of the pole-fringe) may be considered to have a uniform value B_a; then $f(B_a)\ l_a = 1{\cdot}257\ X_a$, where X_a = the ampere-turns required to overcome the armature reluctance. In a preliminary calculation a certain value of the angle of lead is assumed, giving a certain number of back ampere-turns, X_b. The exciting power required between the poles is then $X_p = X_g + X_a + X_b$.

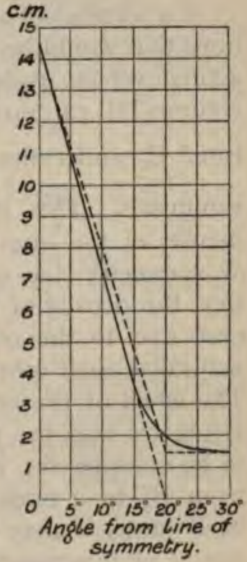

FIG. 5.

At the pole-tip the difference of magnetic potential between pole-tip and core is in C.G.S. units $1{\cdot}257\ \frac{X_g}{2}$. As the line of symmetry is approached, this difference of potential increases until at the line of symmetry it has the value of $\frac{1{\cdot}257\ X_p}{2}$. Between the limits of pole-tip and line of symmetry, the fall of potential due to the armature reluctance may be taken as uniform, or $= \frac{1{\cdot}257\ X_a}{2\,\theta}$ per degree of arc, where θ is half the interpolar angle (Fig. 1). Similarly the fall of potential due to the back ampere-turns is

$\frac{1{\cdot}257\ X_b}{2\,\lambda}$ per degree of arc, where λ is the angle of lead. Thus the difference of potential between the pole-tip and any point A distant from the line of symmetry by an angle a° is $1{\cdot}257\left(\frac{X_g}{2}+\frac{X_a\,(\theta-a)}{2\,\theta}\right)$ up to the angle of lead, and between this and the line of symmetry is

$$1{\cdot}257\left(\frac{X_g}{2}+\frac{X_a\,(\theta-a)}{2\,\theta}+\frac{X_b\,(\lambda-a)}{2\,\lambda}\right) \quad . \quad . \quad . \quad (1)$$

If a number of values for x and a° be taken, the inductions that would be due to the above difference of potential acting over the paths of corresponding length as given by column III. can now be worked out.[1] The values decrease from B_g under the pole to $B_g''' = \frac{1{\cdot}257\ X_p}{2\,(\xi c + l_g)}$ at the line of symmetry. This induction B_g''' may be regarded as the density of the lines that would *enter* the core on the line of symmetry due to one magnet coil; it is at the same time the density of the lines that would *leave* the armature core due to the other magnet coil; the two inductions neutralise each other and the resultant is zero as required. The effect of the second magnet coil between the line of symmetry and the pole-tip furthest away from it still has to be considered; it is measured by an amount decreasing from B_g''' to o under the opposite pole, and as B_g''' is not itself large, it may be taken as decreasing uniformly per degree of interpolar arc,[2] and the value thus given for each degree must be subtracted from the inductions due to the first magnet coil.

In the same armature as before, the angle of lead we assume to be $\lambda = 10^\circ$ with 232 conductors and a total armature current of 160 amperes. The commutator has 116 sectors, and each section of the armature thus consists of one loop of two bars. The time of short-circuit corresponds to an angle of $5{\cdot}2^\circ$; *i.e.*, if the angle of lead be

[1] It may appear an unnecessary refinement to take into account X_a and X_b as in the above approximation, but unless some such allowance is made for them the process cannot be satisfactorily carried out for the entire periphery of the armature.

[2] This method must necessarily be only approximately true, but is probably sufficiently accurate. Mr. J. Fischer Hinnen's method ("Continuous-current Dynamos," p. 217) is open to the objection that it does not make the *induction* assume its normal value near the pole-tip.

reckoned from the line of symmetry up to the centre of the brush, short-circuit begins at 7·4° and ends at 12·6°. The width of one loop corresponds to an angle of $\frac{360°}{232} = 1·55°$. There is, therefore, at the beginning of short-circuit a band of pure back ampere-turns[1] covering $(7·4 - 1·55) \times 2 = 11·7°$, and at the end of short-circuit $(12·6 - 1·55) \times 2 = 22·1°$. There is also the unbalanced pair of loops corresponding in position to the short-circuited loops, but near the trailing pole-tip. These are at the beginning of short-circuit partly back and partly cross ampere-turns, so that there will be little error in assigning one loop to the back ampere-turns and one loop to the cross ampere-turns, while at the end of short-circuit, since they are nearer to the pole-tip, they may both be regarded as cross ampere-turns. Hence at the beginning of short-circuit the band of back ampere-turns has a width of $11·7 + 1·55 = 13·25°$, and at the end of short-circuit a width of 22·1°, and since their variation produces but little effect on the total field, their average width of $\frac{13·25 + 22·1}{2}$, = say 17°, may be taken. Correspondingly the band of cross ampere-turns at the beginning of short-circuit has a width of 162·1° plus one loop (= 1·55°), or a total of 163·65°, and at the end of short-circuit a width of 151·7° plus the width of two loops (= 3·1°), or a total of 154·8°: their average width is therefore $\frac{163·65 + 154·8}{2}$, = say 160°.

The ampere-turns or magneto-motive force between either pole and the line of symmetry can now be calculated in the usual manner.

$$1·257\frac{X_g}{2} = B_g \times l_g = 5{,}040 \times 1·42 = 7{,}150$$

$$1·257\frac{X_a}{2} = \qquad 400 \text{ or } 20 \text{ per degree of interpolar arc}$$

$$1·257\frac{X_b}{2} = 1·257 \times \frac{232}{2} \times \frac{17°}{360°} \times \frac{160}{2} = \qquad 550 \text{ or } 55 \text{ per degree of lead}$$

$$1·257\frac{X_p}{2} \qquad 8{,}100$$

[1] See "Armature Reaction and the Theory of Sparking," *Electrician*, May 21, 1897. For a predetermination of the reversing field in which the short-circuited coils must be regarded as eliminated, the following calculation in detail is necessary; *but if it is merely required to determine the number of lines in the fringe*, X_b *can be simply calculated from the angle of lead.*

Thus for each degree within the angle of lead 20 + 55 = 75 units of magnetic difference of potential, and for each degree without the angle of lead 20 units have to be deducted from the maximum difference of potential between pole-tip and line of symmetry, *i.e.* from $\frac{1·257\ X_p}{2}$.

TABLE II.

Angle from Line of Symmetry. $=a$.	Length of Path in cm.	Diff. of Potential.	Col. 3. / Col. 2.	Deduct	Symm. Induction.	Cross M.M.F.	Cross Induction.	Leading Induction.	Trailing Induction.
0°	14·42	8,100	560	560	0	5,180	359	− 359	359
2°	13	7,950	611	504	107	5,180	398	− 291	505
4°	11·5	7,800	678	448	230	5,180	450	− 220	680
6°	10	7,650	765	392	373	5,180	518	− 145	891
8°	8·6	7,500	872	336	536	5,180	602	− 66	1,138
10°	7·17	7,350	1,025	280	745	5,180	722	+ 23	1,467
12°	5·8	7,310	1,260	224	1,036	5,050	870	+ 166	1,906
14°	4·2	7,270	1,730	168	1,562	4,920	1,170	+ 392	2,732
16°	3	7,230	2,410	112	2,298	4,790	1,596	+ 702	3,894
18°	2·4	7,190	2,990	56	2,934	4,660	1,940	+ 994	4,874
20°	1·95	7,150	3,660	0	3,660	4,530	2,320	+ 1,340	5,980
22°	1·7	7,150	4,200		4,200	4,400	2,590	+ 1,610	6,790
24°	1·5	7,150	4,760		4,760	4,270	2,850	+ 1,910	7,610
26°	1·44	7,150	4,955		4,955	4,140	2,870	+ 2,085	7,825
28°	1·43	7,150	5,000		5,000	4,010	2,810	+ 2,190	7,810
30°	1·42	7,150	5,040		5,040	3,880	2,730	+ 2,310	7,770

When column 6 of symmetrical induction is plotted (thin-line curve, Fig. 6) the interpolar induction is seen to be a concave curve, rising from zero on the line of symmetry and rounding off into the horizontal line of uniform density under the poles.

The cross field due to the cross ampere-turns of the armature next has to be superposed upon the weakened symmetrical field. The paths of the cross field will be approximately the same over the air-gaps as those of the symmetrical field, and will therefore have the same values as in the third column of Table I. Up to $a = \lambda = 10°$, the full number of cross ampere-turns are acting, so that the

magneto-motive force acting on a single air-gap is $1{\cdot}257 \times \frac{232}{2} \times \frac{160^\circ}{360^\circ} \times \frac{160}{2} = 5180$. After passing the angle of lead, the number of cross turns must be reduced down to zero on the diameter at right angles to the line of symmetry; hence for every two degrees $\frac{5180}{80} \times 2 = 130$ C.G.S. units (column 7 in Table II.) must be deducted. The curve of cross-induction which results from the above (column 8 in Table II. and dotted curve of Fig. 6) rises

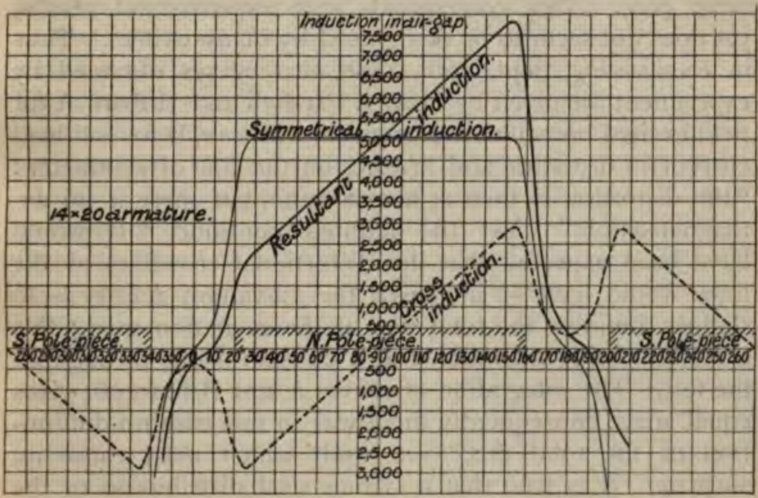

FIG. 6.

gradually as an inclined straight line from zero at a point midway under a pole up to a maximum just short of the pole-tip, and then descends in a concave curve to a second minimum value on the line of symmetry. The curve of resultant field obtained by adding together algebraically the ordinates of the symmetrical and cross field (columns 9 and 10 and thick-line curve of Fig. 6) shows the displacement of the neutral line (in our case $9\frac{1}{2}^\circ$ forwards); the interpolar field falls very rapidly from its high value, B_g'' near the trailing pole-tip, then passes more gradually through zero, and finally rises in a more or less concave curve to its value B_g' under the leading pole-tip.

It may be remarked that with a given magnet excitation

and brushes fixed on the line of symmetry, there can be no reduction in the total field or in the induced E.M.F., however much current is taken out of the armature and however much the field is thereby distorted. This is at once evident from consideration of the resultant field as due to the superposition of two fields. If x cross lines issue from the upper quadrant of the armature core on one side of the symmetrical line, they must return into the core by the lower quadrant on the same side of the symmetrical line: hence the field is as much strengthened in one half as it is weakened under the other half of the same pole. This corresponds with experimental results, yet does not seem to be recognised by many writers. Thus in *Engineering*, Sept. 16th, 1898, two curves obtained by experiment are given by Messrs. Parshall and Hobart, A for field excited but with no current in armature, B for full-load current in armature and brushes on the line of symmetry: "the distortion is then at a maximum, but there is no demagnetisation." Yet the authors continue, "It would have been expected that the distortional crowding of the lines would have so increased the maximum density as to slightly diminish the total flux at the excitation used; this excitation being maintained at a constant value throughout the test. The integration of curves A and B, however, gives equal areas, consequently there was in this case no diminution of the total flux"—a result which need cause no surprise. It is true that a symmetrical distribution of the field requires the minimum excitation or M.M.F., but when there is distortion the additional M.M.F. that is required by the longer and more saturated paths of the lines is just what is supplied by the cross ampere-turns of the armature and corresponds to the self-induction of the armature winding. The only effect of the saturation of the iron of armature or magnet or of the teeth in a toothed core is to cause any two corresponding portions of the cross circuit to have different permeabilities, so that the M.M.F. of the cross ampere-turns, instead of being divided equally over the two air-gaps or portions of the cross circuit, is divided proportionally to their different reluctances. Thus saturation of any part of the magnetic circuit simply reduces the distortion, but never reduces the total flux.

Next when the brushes are given a forward lead in the dynamo or a backward trail in a motor, if the effect of the back ampere-turns be taken into account, as above, in calculating the symmetrical distribution, there is for the same reason no possibility of any further reduction, by the cross ampere-turns, of the total flux of this weakened symmetrical field, however much the distortion may be. Of course if the effect of the total armature ampere-turns on the symmetrical field due to the field-magnet winding be traced, there is both a diminution of the total flux and a distortion of it. In dealing with armature reaction it is therefore important to clearly state whether the effect of the cross ampere-turns on the weakened symmetrical field is alone being traced, or the total effect of the armature on the field of the magnet-winding.

In Professor Carus-Wilson's "Direct-Current Motor," pp. 269–276, three sets of curves are given for a railway motor at half load, full load, and a 50 per cent. overload, the brushes remaining fixed nominally at the no-load position. The first two show practically no reduction of area due to armature reaction; the third shows a considerable reduction, yet if the brushes were originally fixed on the neutral points of a symmetrical field, there should be no reduction. The explanation is probably to be found partly in the increasing internal leakage of the ring armature, and partly in the unsymmetrical character of the four-pole field, two of the poles being salient and carrying exciting coils, while the remaining consequent poles are unwound. The two brushes were not exactly 90° apart, but even so were not both on a neutral point at no load. There is in fact no true line of symmetry in the machine, and the armature ampere-turns were not therefore throughout the experiments pure cross turns, but also possessed a demagnetising component. This is indeed shown by the curves of armature field alone; in these even for the lowest value of the current, when any saturation effect must be inappreciable, the negative areas are larger than the positive areas, although they should be of the same size if simply due to cross ampere-turns.

II.

The results obtained by the above method of calculating the flux-density at different points round the armature have a further application when it is required to determine the total number of lines which form the fringe surrounding the polar faces and add to the voltage of the machine since they are cut by the armature conductors. An approximation which has been commonly used expresses the fringe permeance as that of an equivalent strip of air of uniform width surrounding the pole-face, the length of path through it being the same as the normal l_g, so that when acted on by the difference of magnetic potential X_g, the normal induction B_g holds over its full extent. It is, however, advisable to divide the fringe into two portions, (A) the interpolar fringe along the edges of the pole-pieces parallel with the axis of rotation in the ordinary ring or drum dynamo, and (B) the end-fringe from the flanks of the poles into the ends of the armature core.

The interpolar fringe may be calculated by integrating the induction between the pole-pieces as above determined. The end-fringe may similarly be estimated by assuming the path of the lines into the ends of the core to consist of a straight portion l_g and a portion of a circle struck from the pole-edge as centre (Fig. 7), any lines which spread beyond the edges of the core being neglected. Let a = the distance in cm. by which the core projects at each end beyond the pole, and let b = the length in cm. of the polar arc reckoned on the mean periphery between armature core and pole-face. Then the permeance at each end is

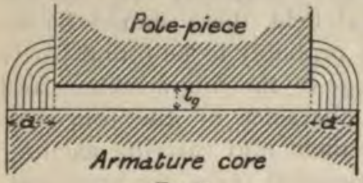

FIG 7.

$$b \int_0^a \frac{dx}{l_g + \xi x},$$

where ξ is again a constant multiplier dependent on the angle which the edge of the pole makes with the surface of the armature core.

The integration of the two divisions of the fringe[1] shows that for dynamos of similar type the interpolar fringe is affected by the ratio $\frac{c}{l_g}$, and the end-fringe by the ratio $\frac{a}{l_g}$. The values of these ratios do not vary much with the size of the dynamo, and average values may be taken which hold within wide limits. Thus for the smooth-core armature, $\frac{a}{l_g}$ is very generally $= 1$, and $\frac{c}{l_g} = 4$; the effective air-gap area can then be expressed as

$$(\mathrm{L} + 1{\cdot}2\, l_g)(b + 1{\cdot}76\, l_g) \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where L = the length of pole-face parallel to the axis of rotation, and b = the breadth of the polar arc. Such an approximate formula has the advantage of indicating the relative importance of the two dimensions L and b, and may be compared with the expression used by Dr. Hopkinson in his first paper on "Dynamo-Electric Machinery," viz.: $(\mathrm{L} + 1{\cdot}6\, l_g)(b + 1{\cdot}6\, l_g)$; the latter giving $\mathrm{L}\, b + 1{\cdot}6\, b\, l_g + 1{\cdot}6\, \mathrm{L}\, l_g + 2{\cdot}55\, l_g^2$, and the former $\mathrm{L}\, b + 1{\cdot}2\, b\, l_g + 1{\cdot}76\, \mathrm{L}\, l_g + 2{\cdot}11\, l_g^2$. The divergence or equality of the two expressions will depend on the proportions of the polar length and arc.

On passing from smooth-core armatures with long air-gaps to short air-space dynamos, the ratios $\frac{a}{l_g}$ and $\frac{c}{l_g}$ are usually considerably increased, and it is shown in the Appendix that the shortening of the air-gap without further alteration except a proportionate reduction of X_g tends to decrease the fringe lines expressed as a percentage of the useful flux under the poles. The change from a long to a short air-space is, however, usually accompanied by the conversion of the smooth core into a toothed core with open slots, and under these circumstances X_g is *not* reduced in the same proportion as l_g, the amount of divergence being dependent on the ratios of the widths of slot and tooth to the air-gap. The induction under the poles in toothed armatures deserves special consideration. If the whole of

[1] For the steps in the mathematical proof the reader is referred to Appendix.

the area of the air under the pole be reckoned as in a smooth-core armature, and this be divided by the normal length of the air-gap, it is evident that too high a value for the permeance is obtained; for the entire area of the air-gap is thereby assumed to be uniformly filled with the same density of field, whereas the lines from the sides of the teeth follow a longer path than those from the tips, and so are less dense. If, on the other hand, the average area of teeth and pole-face and the average length of path be taken on the assumption that all the lines enter into the faces of the teeth, too small a value for the permeance is obtained, since a large portion of the air-space may not be utilised. The following approximation has been found by

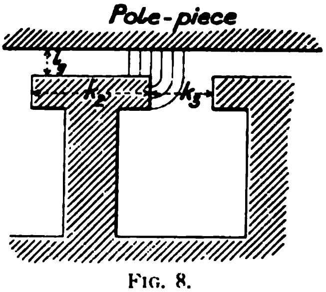

FIG. 8.

the writers to yield results which agree well with experiment, and is suggested as a basis for calculating the permeance of the air-gap in toothed armatures. Let the lines be assumed to pass in straight paths from the pole-face to the face of the teeth, and in straight lines joined by arcs of circles to the sides of the teeth within the slot (Fig. 8). The permeance corresponding to a narrow strip at the side of a tooth is then $\frac{L\,d\,x}{l_g + \xi\,x}$; and the total permeance of the space between the side of a tooth and the centre line of the slot is

$$L\int_0^{\frac{k_3}{2}} \frac{d\,x}{l_g + \xi\,x} = \frac{L}{\xi}\log_e \frac{\xi\,k_3 + 2\,l_g}{2\,l_g}.$$

If the side of the opening into the slot be perpendicular

to the face of the tooth, $\xi = \frac{\pi}{2}$, and the permeance of one side of a tooth

$$= \frac{2 \times 2{\cdot}3\,\mathrm{L}}{\pi} \log \frac{\pi k_3 + 4 l_g}{4 l_g}.$$

The total permeance of the air-gap under the pole is therefore

$$\mathrm{P} = \mathrm{L}\left\{\frac{k_2}{l_g} + \frac{9{\cdot}2}{\pi} \log\left(\frac{\pi k_3 + 4 l_g}{4 l_g}\right)\right\} \times \text{No. of slots under the pole.}$$

$$= \mathrm{L}\left\{\frac{k_2}{l_g} + 2{\cdot}93 \log\left(1 + {\cdot}785 \frac{k_3}{l_g}\right)\right\} \times \frac{b}{k_2 + k_3} \quad . \quad . \quad . \quad (3)$$

while the permeance of a smooth-core armature with the same dimensions would be

$$\frac{\mathrm{L}\,b}{l_g} = \mathrm{L}\left(\frac{k_2 + k_3}{l_g}\right) \times \frac{b}{k_2 + k_3}.$$

A table[1] can then be constructed for the values of m, or the ratio

$$\frac{k_2 + k_3}{l_g} : \frac{k_2}{l_g} + 2{\cdot}93 \log\left(1 + {\cdot}785 \frac{k_3}{l_g}\right),$$

these values being the factors by which the air-gap permeance under the pole-face as calculated for a smooth-core armature must be divided to obtain the corresponding permeance for a slotted armature; or *vice versâ*, m is the factor by which the X_g, as calculated for a smooth core, must be multiplied to obtain the X for the toothed armature.

Finally it remains to ask how far a formula for the useful fringe which is based on a smooth armature will hold good for a toothed core. An inspection of Table IV. shows that k_2 and k_3 remaining constant, the longer l_g becomes, *i.e.* the less the ratios $\frac{k_2}{l_g}$ and $\frac{k_3}{l_g}$ are, the more nearly does the air-gap permeance of the slotted armature approximate to that of the smooth core. In other words, the longer the path of the lines through the air into the teeth,

[1] See Appendix, Table IV.

the less is the effect of the broken surface of the armature. Moreover, X_1 and X_4 bear a larger proportion to X_2 in the toothed armature, and the increase in the fringe lines which would result therefrom may be taken as balancing the decrease which there would be close up to the pole-edges owing to the presence of the slots. The number of fringe lines may therefore be taken as the same in smooth-core and in slotted armatures for the same value of X_g. The problem that is presented to the dynamo designer is, however, to calculate the value of X_g for a given total number of lines Z_g in the air-gap both under and outside the pole-face. In order then to be able to divide the total permeance by m as given in Table IV., we must first multiply l' and b', or the constants K_1 and K_2 of Tables II. and III.[1] by m; for

$$\frac{1}{m}(L + 2l'm)(b + 2b'm) = \frac{Lb}{m} + 2l'b + 2Lb' + 4l'b'm.$$

This operation produces the required effect except in regard to the corner fringe lines, but as these form but a small proportion of the whole, the error thereby introduced may be neglected. The total air-gap permeance of a toothed armature may then be conveniently expressed as

$$\frac{(L + mK_1)(b + mK_2)}{m},$$

while the average induction under the pole-face or the quotient of the total useful flux divided by the effective area of the air-gap is the same both in the smooth and slotted armature, viz.,

$$B_g = \frac{Z_g}{(L + K_1)(b + K_2)}.$$

APPENDIX.

A.—INTERPOLAR FRINGE.

By equation (1), the difference of magnetic potential between the pole-tip and any point A distant from the line of symmetry x cm. (Fig. 9) is

$$1{\cdot}257\left(\frac{X_g}{2} + \frac{X_1}{2c}(c - x) + \frac{X_4}{2c}(c - x)\right).$$

[1] See Appendix.

where d is the distance measured on the periphery of the core corresponding to the angle of lead, and the last term is no longer to be reckoned when $x = d$. The length of path of the lines is $\xi(c-x) + l_g$, the slight inaccuracy in this assumption which has been pointed out being negligible in its effect on the total. Hence the lines of the fringe along the pole-edge of length L and entering any small strip of width dx parallel to the pole-edge and passing through A are

$$\frac{1 \cdot 257\left(\frac{X_g}{2} + \frac{X_a(c-x)}{2c} + \frac{X_b(d-x)}{2d}\right). L\,dx}{\xi(c-x) + l_g} - \frac{1 \cdot 257\, X_p}{2(\xi c + l_g)} \cdot \frac{c-x}{c} \cdot L\,dx,$$

the latter term being approximately the deduction which must be

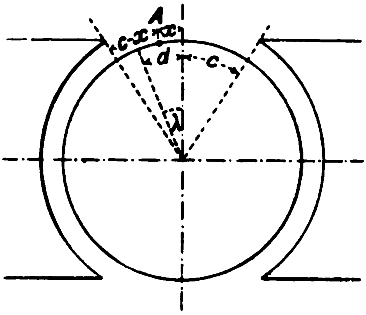

FIG. 9.

made to allow for the influence of the opposite pole. This negative term may be summed up at once as

$$= - \frac{1 \cdot 257\, X_p \,.\, c\, L}{4(\xi c + l_g)}.$$

The other items may best be summed up separately; thus

$$\frac{1 \cdot 257\, X_g \,.\, L}{2} \int_c^o \frac{dx}{(\xi c + l_g) - \xi x} = \frac{1 \cdot 257\, X_g \,.\, L}{2} \cdot \frac{2 \cdot 3}{\xi} \cdot \log \frac{\xi c + l_g}{l_g}$$

$$\frac{1 \cdot 257\, X_a \,.\, L}{2c} \int_c^o \frac{(c-x)\,dx}{(\xi c + l_g) - \xi x} = \frac{1 \cdot 257\, X_a\, L}{2c} \cdot \frac{1}{\xi}\left(c - \frac{2 \cdot 3\, l_g}{\xi} \,.\, \log \frac{\xi c + l_g}{l_g}\right)$$

and

$$\frac{1 \cdot 257\, X_b \,.\, L}{2d} \int_d^o \frac{(d-x)\,dx}{(\xi c + l_g) - \xi x}$$

$$= \frac{1 \cdot 257\, X_b \,.\, L}{2d} \cdot \frac{1}{\xi}\left(d - \frac{2 \cdot 3\{\xi(c-d) + l_g\}}{\xi} \log \frac{\xi c + l_g}{\xi(c-d) + l_g}\right)$$

Thus the total number of lines in the two interpolar fringes is

$$1{\cdot}257\,L\left[\frac{2\cdot3X_e}{\pi}\log\left(1+\frac{\pi c}{[illegible]}\right)+\frac{X_e}{\pi}\Big\{[illegible]-\frac{2\cdot3\,l_e}{\pi}\log\left(1+\frac{\pi c}{l_e}\right)\Big\}\right.$$

$$\left.+\frac{X_e}{\pi d}\Big\{d-\frac{2\cdot3}{\pi}\,[illegible]\log\frac{[illegible]}{\pi c-d-l_e}\Big\}-\frac{X_e\,[illegible]}{2\pi c+l_e}\right]$$

E.—THE END FRINGE.

The permeance at each end of the armature is

$$\int_0^{d}\frac{dx}{[illegible]+\theta x}=\frac{1}{\theta}\log\frac{[illegible]}{[illegible]}$$

and this is acted on by $\frac{1{\cdot}257\,X_e}{2}$ throughout. The angle which the edge of the pole makes with the surface of the armature is usually 90° as shown in Fig. 7, whence $\theta=\frac{\pi}{2}$, and the permeance of both ends combined is

$$\frac{4\times2\cdot3}{\pi}\,[illegible]\log\left(1+\frac{\pi}{2}\cdot\frac{d}{[illegible]}\right)$$

$$=2{\cdot}93\,[illegible]\log\left(1+1{\cdot}57\frac{d}{[illegible]}\right)$$

Thus the total number of lines in both the side and end fringes of a pole are

$$1{\cdot}257\left[X_e\Big\{\frac{2\cdot93}{2}\log\left(1+1{\cdot}57\frac{d}{[illegible]}\right)+\frac{2\cdot3}{\pi}\log\left(1+\frac{\pi c}{[illegible]}\right)\times L\Big\}\right.$$

$$+\frac{X_e}{\pi}\Big\{[illegible]-\frac{2\cdot3\,[illegible]}{\pi}\log\left(1+\frac{\pi c}{[illegible]}\right)\Big\}\times L$$

$$+\frac{X_e}{\pi d}\Big\{d-\frac{2\cdot3}{\pi}\,[illegible]\log\frac{\pi c+l_e}{\pi c-d-l_e}\Big\}\times L$$

$$\left.-\frac{X_e\,[illegible]}{2\pi c+[illegible]}\times L\right]\qquad(4)$$

If l_e and X_e are reduced in the same proportion, i.e. if the dynamo be converted from a long-air-space to a short-air-space machine without further alteration, the end permeance and the first item of the interpolar fringe are by no means increased in proportion, so that the percentage of useful lines outside the bored face of the pole decreases. On the other hand, X_a and X_e remain the same, and l_e in the minus quantity of the third or X_a item is decreased more than the logarithms are increased, so that the third item increases. So, too, the last minus item is considerably decreased. Hence on the whole there is a

decrease in the percentage of useful lines due to the fringe, but this effect is not so marked as might at first sight be supposed.

Since for approximate purposes we may neglect X_a and X_b in comparison with X_g in dynamos with smooth core and long-air-space, in which case X_p becomes equal to X_g, the complete expression for the total number of useful lines entering the armature core both underneath the polar face and outside of it may be put in the simpler form

$$1{\cdot}257 \frac{X_g}{2} \left[\frac{L\,b}{l_g} + 2{\cdot}93 \log\left(1 + 1{\cdot}57 \frac{a}{l_g}\right) b + \left\{ \frac{4{\cdot}6}{\xi} \log\left(1 + \frac{\xi\, c}{l_g}\right) - \frac{c}{\xi\, c + l_g} \right\} \times L \right] \quad . \quad . \quad . \quad . \quad (5)$$

The expression within the brackets [ ] gives the total permeance of one air-gap as so far determined, and may also be written

$$\frac{1}{l_g} \left[L\,.\,b + 2{\cdot}93 \log\left(1 + 1{\cdot}57 \frac{a}{l_g}\right) b\,.\,l_g + \left\{ \frac{4{\cdot}6}{\xi} \log\left(1 + \frac{\xi\, c}{l_g}\right) - \frac{c}{\xi\, c + l_g} \right\} \times L\,.\,l_g \right] \quad . \quad . \quad . \quad (6)$$

In Fig. 10 let the central rectangle A have sides of length L and b

FIG. 10.

respectively. Its area will then represent the first term within the bracket. Produce the "L" sides of A in both directions for a distance

$$l' = \frac{2{\cdot}93}{2} \log\left(1 + 1{\cdot}57 \frac{a}{l_g}\right) l_g,$$

so as to form the two rectangles B, B. This distance l' is then the effective width of the end fringe if the lines be supposed to have a path uniformly of the normal length l_g; and the area of the two rectangles together

$$= 2{\cdot}93 \log\left(1 + 1{\cdot}57 \frac{a}{l_g}\right) b\,.\,l_g,$$

which is the second term of the bracket. Similarly by making

$$b' = \tfrac{1}{2} \left\{ \frac{4{\cdot}6}{\xi} \log\left(1 + \frac{\xi\, c}{l_g}\right) - \frac{c}{\xi\, c + l} \right\} l_g,$$

the area of the two rectangles C. C together equal to the third term is obtained, b' being the effective width of the interpolar fringe.

The figure thus obtained is a complete rectangle less the four corners shown shaded. These corners with a very near degree of approximation represent $\frac{1}{l_g} \times$ the permeance of the corner fringes, which have hitherto not been taken into consideration. The area of the complete rectangle thus gives the total air-gap permeance divided by l_g

$$= \frac{1}{l_g}\left\{ L + 2\cdot93 \log\left(1 + 1\cdot57\frac{a}{l_g}\right) l_g \right\} \left\{ b + \left(\frac{4\cdot6}{\xi}\log\left(1+\frac{\xi c}{l_g}\right) - \frac{c}{\xi\; c+l_g}\right) l_g \right\}$$

$$= \frac{1}{l_g}\left\{ L + K_1 . l_g \right\} \left\{ b + K_2 . l_g \right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

and B_g or the quotient of the total useful flux divided by the effective area of the gap is

$$\frac{Z_g}{(L + K_1 l_g)(b + K_2 l_g)}.$$

The following tables of K_1 and K_2 for varying values of $\frac{a}{l_g}$ and $\frac{c}{l_g}$ are then convenient for quickly calculating the effective widths of the fringes.

TABLE II.

$\frac{a}{l_g}$	Values of $K_1 = 2\cdot93 \log\left(1 + 1\cdot57\frac{a}{l_g}\right)$
1·00	1·2
1·25	1·38
1·5	1·54
1·75	1·68
2·00	1·81

TABLE III.

$\frac{c}{l_g}$	Values of $K_2 = \frac{4{\cdot}6}{\xi}\log\left(1+\frac{\xi c}{l_g}\right) - \frac{c}{\xi c + l_g}$					
	$\xi = 1{\cdot}6$	1·8	2	2·2	2·4	2·6
4	1·96	1·85	1·76	1·67	1·59	1·52
5	2·19	2·06	1·95	1·84	1·75	1·67
6	2·38	2·23	2·10	1·99	1·89	1·80
7	2·56	2·39	2·25	2·12	2·01	1·91
8	2·70	2·52	2·37	2·24	2·12	2·01

For smooth-core armatures the average values are $\frac{a}{l_g} = 1$, $\xi = 2$, and $\frac{c}{l_g} = 4$, whence the virtual air-gap area is

$$(L + 1{\cdot}2\, l_g)\,(b + 1{\cdot}76\, l_g) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

TABLE IV.

Values of m.

$\frac{k_3}{l_g}$	$\frac{k_2}{l_g}$						
	·5	·75	1·0	1·25	1·5	1·75	2·0
·5	1·09	1·07	1·06	1·05	1·04	1·04	1·03
·75	1·15	1·12	1·10	1·09	1·08	1·07	1·06
1·00	1·21	1·18	1·15	1·13	1·12	1·11	1·10
1·25	1·28	1·24	1·21	1·18	1·16	1·15	1·13
1·5	1·34	1·29	1·26	1·23	1·21	1·19	1·17
1·75	1·41	1·35	1·31	1·28	1·25	1·23	1·21
2·0	1·47	1·41	1·36	1·33	1·30	1·27	1·25

Owing to the necessity of avoiding eddy-currents in the pole-pieces the maximum value of $\frac{k_3}{l_g}$ should not exceed 2, and the minimum value to avoid too much inductance will not be less than say ·5.

NOTICE.

1. The Institution's Library is open to members of all Scientific Bodies, and (on application to the Secretary) to the Public generally.

2. The Library is open (except from the 14th August to the 16th September) daily between the hours of 11.0 a.m. and 8.0 p.m., except on Thursdays, and on Saturdays, when it closes at 2.0 p.m.

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The Three Hundred and Forty-Fourth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday evening, March 22nd, 1900, Professor J. PERRY, F.R.S., Vice-President, in the Chair.

The Minutes of the Ordinary General Meeting held on March 8th, 1900, were read and approved.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Charles Sheldon Thomson, M.Sc.

From the class of Associates to that of Members—

August Eckstein.

From the class of Students to that of Associates—

William Stuart Boyd.
Claud Crompton.
James Albert Seager.

Messrs. J. Roberts and H. M. Sayers were appointed scrutineers of the ballot for new members.

Donations to the Benevolent Fund were announced as having been received since the Annual General Meeting on February 9th, amounting to £158 16s. 6d. in all, from

Dr. F. H. Bowman; W. T. Henley's Telegraph Works Company, Limited; The Incandescent Electric Lamp Company, Limited; The Aron Electricity Meter, Limited; Professor Aron; The General Electric Company, Limited; Messrs. Falk, Sladelmann & Co.; Messrs. P. Ormiston & Co.; Mr. H. Edmunds, Mr. S. W. Martyn; The British Insulated Wire Company, Mr. H. Hellman, Messrs. S. Heine Brothers, Messrs. J. C. Fuller & Sons, Messrs. Pinckbeck Brothers, The Sloan Electric Company, Hooper's Telegraph Works Company, Limited; Mr. F. Samuelson, Messrs. E. Matthews & Co., and Mr. Allan F. Beach.

Donations to the Building Fund were announced as having been received since the last meeting from Messrs. B. Balaji, R. J. Browne, T. B. Murray, and Edward Dixon.

The thanks of the meeting were accorded to the donors.

STORAGE BATTERY PROBLEMS.

By E. J. WADE, Associate.

PART I.

Every one who has given any thought to the principles underlying the chemical storage of electrical energy must at some time or another have been struck by the extraordinary fact that in spite of the theoretical reversibility of every galvanic combination—and their name is legion—yet one and one only out of the whole number is commercially feasible; so that at the present day storage cells may at once be classified thus:—

Practical: Lead—sulphuric acid—lead peroxide cells.

Unpractical: All others.

Such, however, being the state of affairs, it appears a fairly safe inference that this special combination must possess distinctive features not shared by any other, or at least by any other whose cost is not prohibitive; and on examination this soon proves to be the case.

Several noteworthy features, each contributing towards its success, might be cited; but the really unique characteristic of the combination as a whole lies in the fact that the electrodes, the active materials, and the compounds produced from them are, under every normal condition of use, all insoluble in the electrolyte employed.

In every other galvanic combination with which commercial storage has been attempted, one or both of the electrodes or active materials have been soluble, and this solubility has in the long run invariably proved fatal. If a soluble negative is used, and the majority of the attempts made have been in this direction by substituting zinc for lead, the metal can only be redeposited effectively under certain conditions, and for a limited number of times. If the positive is soluble, as for instance in the early attempt of Messrs. Thompson & Houston to adapt the Daniell cell to storage purposes, there is the additional trouble that its soluble salt inevitably reaches sooner or later to the negative electrode, where it is also deposited and sets up destructive local action. The latter objection of course applies to all kinds of fluid depolarising agents.

For these amongst other reasons, the difficulties in the way of constructing successful storage cells with soluble electrodes have up till now proved insurmountable; while a second combination which follows the lines of the lead accumulator and only forms insoluble compounds at both poles yet remains to be discovered. So advantageous, however, to the electrical industry might be the results attending the introduction of an altogether new type of cell, possessed of greater capabilities than those now in use, and so considerable should be the reward of its inventor, that the subject well merits further investigation and experiment in both directions; but I incline to the apparently paradoxical opinion that the solution of the problem, if any, will be an insoluble one. Also, I think that considering the extent to which the field has already been worked over, success is most likely to be attained by the utilisation of some of the less studied and more obscure reactions into which the metals enter.

On turning our attention again to the lead—sulphuric acid—lead peroxide combination, the storage cell of commerce, a second remarkable fact encounters us. We find that although these cells have now been manufactured and used on a large commercial scale for close upon twenty years, and during that time have been the subject of frequent laboratory investigations, it is not yet definitely settled what are the exact physical and chemical changes taking place in them. Now this is a most unsatisfactory

state of affairs. If, as is not impossible, we may always have to depend on this one combination for all practical electric storage, it becomes of the greatest importance to determine whether its capabilities have already been developed to their utmost limits; or, if not, in what directions further advances are possible; but how can this be done without any certain basis to work from?

The last fifteen years have witnessed more improvements in lead accumulators than might at first sight be apparent from an inspection of the cells themselves, for they have consisted not so much in any radical alterations of type, as in a better understanding of the methods of treatment, the processes of manufacture and the proper proportions and relations of the various component parts. A general readjustment, in fact, of many details all tending towards one common end, and resulting in an apparatus far better able to meet the requirements of its users.

On the other hand there are indications that empirical experimenting has nearly reached its limits, for I do not think that many of these improvements have been made very recently. It is true that within the last few years there have been numerous attempts, as the Patent Office records bear eloquent witness, to reduce the weight of the cells in order better to adapt them for traction purposes generally, but more especially for use in electric automobiles. Time and trial have already pronounced their judgment on most of them. A few survive, but whether their *sum total* of usefulness shows any increase over earlier types appears to be doubtful. It has, of course, long been known that weight could be considerably reduced at the expense of life and durability, if circumstances rendered it desirable to do so; but unless the one factor is improved without depreciating the other, that in itself hardly constitutes any real advance. On this question of weight versus durability, however, the views of members who have had actual experience with the later and lighter types of cells would be of much use and value.

The preceding considerations must be my excuse for devoting a considerable portion of this paper to a discussion
racic. of the theoretical and chemical questions connected
that the elec· for if I can help to throw light, or be the
produced from any further light thrown on this part of
of use, all insolu

the subject, I may after all be doing the most practical service possible.

Personally I have no doubt that, as far as any explanation based solely on the results of chemical analysis can help us, the "double sulphation" theory gives the nearest approximation to what does or should take place on discharge. Put shortly, this theory maintains that on discharge, lead at the negative and lead peroxide at the positive react with sulphuric acid in the electrolyte and are both converted into normal lead sulphate, water being eliminated at the positive; and the reactions are expressed chemically in the following well-known equations:—

At the negative electrode—

$$Pb + SO_4 = PbSO_4 ;$$

at the positive electrode—

$$PbO_2 + H_2 + H_2SO_4 = PbSO_4 + 2H_2O ;$$

and the sum of the reactions at both electrodes—

$$Pb + 2H_2SO_4 + PbO_2 = 2PbSO_4 + 2H_2O.$$

I have advisedly said that this is the "nearest approximation" to the discharge reactions, for the above statements, if taken literally and without considerable mental reservations, especially with regard to the very definite facts embodied in the equations, are probably inaccurate, and certainly open to question in nearly every particular.

In the first place, it is doubtful whether negative active material is simply lead, Pb, using the word and symbol without any qualification and in their usual sense as applied to the ordinary metallic form of that substance. If for a negative electrode of spongy metal electrolytically prepared, we substitute one containing metallic lead in as fine a state of subdivision as it is possible to procure it by purely mechanical means, such, for instance, as lead dust or lead wool, no practical storage capacity can be obtained. The evidence seems to show that the spongy lead at the negative, in addition to its extreme porosity, possesses distinctive *chemical properties* and is a true allotropic

modification which enters into combination somewhat differently to how lead does in its normal condition.

M. Darrieus, who was, I believe, the first to propound this view of the nature of the negative active material, has shown that the E.M.F. of various galvanic combinations in which electrolytically prepared lead is employed is ·3 to ·4 volts higher than that obtained by substituting ordinary sheet metal. This proves that the former must be in an abnormally active state; and the same fact is shown chemically by the extreme readiness with which negative active material oxidises when exposed to the action of the air, the combination taking place so rapidly that the heat liberated very considerably raises the temperature of the electrode.

Secondly, there is some reason for believing that the positive active material is not normal lead peroxide, PbO_2, if we adapt as our standard for that compound the residue left after treating red lead with dilute nitric acid, which certainly has a proportional composition agreeing with this formula. Mr. FitzGerald drew attention to the point in 1890, the evidence being of a somewhat similar nature to that just adduced in the case of the negative active material, namely a difference in the E.M.F.s generated by the two substances. The probability is therefore suggested that the crystalline electrolytically prepared peroxide of a positive electrode is also an allotropic modification and not identical with the amorphous anhydrous peroxide obtained by chemical means; but in this case the matter is complicated by Mr. FitzGerald's further observation that, as far as his experience goes, the electrolytic peroxide is always hydrated. While then, for lack of more definite knowledge, still using the formula PbO_2, it must be considered only provisionally correct.

Thirdly, the usual equations are very misleading as to the nature and composition of the discharge products. Quite apart from the confirmation afforded by analysis, the most casual examination shows that the active materials are never fully sulphated by the time the discharge is completed, no matter under what conditions it is taken nor how small the quantity of active material employed. Even with the mere [illegible] of spongy lead and lead peroxide the same fac[illegible] the eye.

This is indeed only one aspect of the more general objection which has been urged by Mr. FitzGerald for many years past, that the very definite discharge equation must have some equally definite E.M.F. corresponding to it, no matter what may be its absolute value; whereas the E.M.F. of a discharging cell is a constantly varying one. Even granting that the small but rapid drop of E.M.F. generally observed during the first few minutes of a discharge is the result of special reactions not allowed for in the equation, and that the complete and sudden loss of voltage which ends the discharge is also brought about by causes beyond its scope, yet the fact remains that throughout the normal and useful portion of the discharge lying between these two, the E.M.F. is slowly but steadily falling all the time.

Even the assumption of the partial conversion of either of the active materials into normal lead sulphate, $PbSO_4$, under ordinary discharge conditions, is not to be reconciled with their observed behaviour, which is in many respects incompatible with the presence of large percentages of that substance. To instance one. Normal lead sulphate is probably quite irreducible if not unperoxidisable, in a dilute sulphuric acid electrolyte of the strength ordinarily used in storage cells, *provided all the materials are absolutely pure*, for the smallest traces of impurities make a remarkable difference in this respect. But however that may be, there is no doubt as to its being acted upon with extreme slowness, under the most favourable conditions in admixture with other materials of a more conductive nature, and then only with an excessive outlay of energy in proportion to the result obtained; whereas both the active materials can be brought back to their original states of lead and lead peroxide with great rapidity and the expenditure of very little more current than is theoretically necessary. This discrepancy, as well as the almost complete masking of other properties of the normal sulphate, can hardly be explained as due to its state of extreme subdivision and intimate admixture with unaltered active material, for under certain well-known conditions of treatment it does appear in full possession of its distinctive colour and with its non-conductivity and irreducibility aggressively in evidence.

A good deal more might be said as to these and other reasons which forbid our accepting the double sulphation theory in its simplest form except as a purely provisional statement; but without stopping to discuss them further, I will give a very brief summary of what I believe to be the real nature of the various changes that go on in the cells.

Commencement of Discharge.—The active materials of fully charged negative and positive electrodes consist of lead and lead peroxide respectively, but *both in allotropic or polymeric states, and possessed of a molecular structure far more complex than is represented by the formulæ* Pb *and* PbO_2.

Normal Discharge.—On discharge, no molecules of lead or lead peroxide are wholly and directly converted into normal lead sulphate; but, *still maintaining their complex molecular structure*, they pass through a long series of true compounds containing SO_4 in gradually increasing proportions. In this way, no portion of the active materials loses its conductivity nor is cut off from electrical connection with the remainder, and its easy and rapid desulphation on recharge is thereby provided for.

End of Discharge.—This absorption of SO_4 does not and cannot go on until the molecules are fully sulphated, because at some intermediate stage their electrical resistance, which previously has only been increasing slowly, commences to go up with extreme rapidity. This change is necessarily accompanied by an equally sudden and rapid fall in the cell's potential difference, which soon passes below the usual limiting value; but if the circuit is still maintained the internal resistance goes on rising, and in a short time the potential difference is reduced practically to zero. Most probably the rapid acceleration of resistance sets in when the molecules of active material have attained the respective proportional compositions $Pb_2O_2SO_4$ and Pb_2SO_4.

Reversal.—If the current is kept flowing through the cell by means of an external E.M.F., reversal now commences. No further sulphation of the active materials takes place, the proportion of SO_4 present in the molecules remaining constant throughout this stage, but lead gradually passes over to peroxide at the negative, and *vice versâ* at the

positive, until their composition, as given above, is exactly reversed. Here again the change is only effected through a whole series of intermediate compounds, and *the molecules retain their complex structure intact.*

Recharge.—The recharge of a cell, whether in continuation of the reversal or as the normal charge following on a discharge, consists essentially in the gradual withdrawal of SO_4 from the molecules until allotropic lead and lead peroxide are again reproduced. Other reactions on charge are only incidental so far as the active materials are concerned.

"*Sulphating.*"—Using this word in its well-understood technical sense, sulphating consists in the breaking up of the complex molecules, containing more or less SO_4, into a number of simpler and independent molecules of normal lead sulphate and of lead or lead peroxide. This rearrangement of structure destroys the continuity and conductivity of the active material, and at the positive, if not at both electrodes, is accompanied by an increase in bulk which may lead to the breaking up of itself and its support. Nothing further is needed to bring about this change than rest on open circuit; but the instability of the compounds appears to be largely proportional to the percentage of SO_4 present either in the active materials or in the electrolyte; that is to say, it increases with the extent to which the cell is discharged and with the strength of acid used in it. Probably local action, due to impurities and other causes, plays an important part in facilitating the same result; and a still more favourable condition is the excessive weakening of the acid electrolyte in the pores of the active materials during discharge.

It will be observed that the foregoing views are entirely based on the possibility of the active materials existing in two distinct molecular states; an allotropic one involving a complex structure and, although unstable, corresponding to the normal and healthy working condition of the cell, and a simpler and more stable one, but identical with the undoubtedly deleterious condition known as "sulphated." From its very nature direct proof of this assumption is almost impossible, and as the indirect arguments are mostly theoretical and require a consideration of some of the purely chemical characteristics of the lead compounds,

have dealt with them separately in the second part of this paper. In it I have also traced out in more detail the different changes that must ensue in the cell according to this hypothesis, for the way in which it enables us to furnish a consistent and reasonable explanation of the cell's behaviour in every respect appears to me to furnish one of the strongest arguments in its own support.

One obvious objection to the theory may be referred to here. Involving, as it does, the formation of numerous sulphated lead compounds of indefinite composition, it runs counter to the usual text-book chemistry, which draws an absolutely hard and fast line between chemical compounds and mechanical mixtures. In recent years, however, the rapid advances made in our knowledge of physical chemistry have provided much evidence obtained from very different sources, such as the properties and behaviour of alloys and of aqueous solutions, all tending to prove that substances may exist whose components do not apparently follow the law of combination in multiple proportions, and yet must in other respects be regarded as true molecular and chemical compounds. Of this nature are the compounds normally formed during the discharge, reversal, and recharge of a lead cell.

From this basis of theory we can now proceed to the consideration of some points of more direct practical importance. In the first place, if it is true that the molecules of active material *inevitably* cease liberating electrical energy when they are about 50 per cent. sulphated (giving on analysis 44 per cent. by weight of unaltered peroxide at the positive, and 40·5 per cent. of uncombined lead at the negative), owing to a sudden and large increase in their electrical resistance at that stage; then the actual performance of commercial storage cells approaches far nearer to the theoretically possible maximum than has hitherto been supposed.

If it *could* be effected electrically, the complete sulphation of 1 lb. of lead would liberate 118·5 ampere-hours, and the complete reduction to sulphate of 1 lb. of lead peroxide, 102·5 ampere-hours; but I consider that the real standard of perfection should be just half these values, that is 59·25 and 51·25 ampere-hours respectively. (The figur[illegible] :roxide are based on the assumption that its

proportional composition is PbO_2: if it is hydrated its possible output will be slightly less.)

The active materials of well designed and properly formed Planté type electrodes do, I think, often approximate to these outputs when discharging at low rates, say in nine to twelve hours; and, judging from the analyses of the positive paste in the E.P.S. cell tested by Professor Ayrton in 1890, the active material of Faure type electrodes is also capable of doing so; but in this special instance the previous treatment of the cell was exceptionally favourable, and as, on a 12-hour discharge rate, its capacity came out about 33 per cent. above its listed value, it had evidently been worked up to a state of efficiency but seldom attained, still less maintained.

In practice, pasted electrodes hardly ever give more than 30 to 40 ampere-hours per pound of positive or negative active material; while about half these values is probably a more usual figure: for, although the specific output of the active materials in new electrodes is often high, yet in many cases it decreases considerably with use; and if the electrodes are of faulty design or manufacture, or the cells not properly looked after, it may drop to almost any extent.

However, with all electrodes, whether of the Planté or Faure type, there is a very considerable falling off in the specific output of the active materials as the discharge rate is increased. The exact amount and curve of decrease varies with every different make of cell, but the best of them do not, at a three-hour rate, give more than two-thirds to three-quarters of their output on a nine to twelve-hour rate; while if discharged in one hour, their output is only about one-half or even less. After all then, there is still some considerable margin left for improvements in the ratio of output to weight, especially when rapid discharges are required; and these are often precisely the cases where a reduction in weight would be of the most importance and use, provided it were not effected at a sacrifice of durability.

It is evident that to obtain the maximum output from any active material the electrolyte must have access to each of its individual molecules so as to include them all in the electrolytic circuit; and its porosity therefore must be thoroughly molecular. That is to say, in addition to the spaces that exist between the small visible particles of

material, each of these particles must itself be porous throughout. Most negative active material necessarily fulfils this condition, as the electrolytic reduction of the oxide or other insoluble salt employed must leave each molecule of lead surrounded by a space, also of molecular proportions, previously occupied by the other elements in combination with it.

The case of positive active material is somewhat different. If it is prepared from salts, such as lead sulphate or lead chloride, possessing about twice the bulk or half the density of lead peroxide, its molecular porosity is initially provided for just as it is in negative active material; but if it is obtained from litharge or minium or other compounds whose density is about the same as that of the peroxide itself, it is not at first sight evident how it can possess any porosity beyond the spaces between its visible particles; while if it is produced from solid metallic lead by a formation of the Planté type, no porosity of any kind seems to be provided for. In all these cases, however, the materials, before being peroxidised, no doubt pass through an intermediate stage of partial sulphation accompanied by a proportional increase in bulk, so that in this respect the conditions are to some degree the same as if lead sulphate had been the original raw material. That some such growth of the positive active material does take place during its first formation is shown by the expansion of its support which almost invariably attends this process, whether the electrodes be of the formed or pasted variety.

But although the pores and spacing are there, they are quite inadequate to contain anything approaching the amount of electrolyte required for the full discharge of the active material surrounding them. Negative active material sufficiently porous to hold its own volume of liquid will have what is sometimes incorrectly called a "density" of 5·7 (half the density of solid lead, 11·4) or, as I prefer to term it, a 50 per cent. porosity; and this is a good average figure for the spongy lead in commercial cells. Lead peroxide being bulkier than lead, positive active material is, as a rule, not nearly so porous, and a good average material will certainly not have more than a 33 per cent. porosity, or a so-called density of about 6·3 (two-thirds that of solid PbO_2, 9·45), and it will only contain one-half its own volume of electrolyte.

Now solid lead requires about twenty-four times, and solid peroxide about sixteen times their own volumes of dilute sulphuric acid, sp. gr. 1·200, for their 50 per cent. sulphation, with a fall of acid strength to sp. gr. 1·150; so that, negative and positive active materials of good average porosity can only contain about $\frac{1}{24}$th and $\frac{1}{32}$nd respectively of the quantity of electrolyte necessary for their complete discharge under these conditions. Even if the whole of the acid were abstracted from the solution in the pores, leaving nothing there but water, then the negative and positive active materials could respectively contain only about $\frac{1}{8}$th and $\frac{1}{11}$th of the necessary amounts of 1·200 acid, or about $\frac{1}{7}$th and $\frac{1}{10}$th if 1·300 acid were employed.

These figures show very clearly how entirely the output of a lead cell is dependent on the diffusion of acid from the main body of the electrolyte into the depleted solution in the pores of its active materials. As long ago as 1889 Messrs. Duncan and Wiegand called attention to some of the results that must ensue if proper diffusion were not provided for; and Messrs. Gladstone and Hibbert, in their communication to this Institution in 1892, also indicated some of the effects probably due to this cause. In the latter instance, however, they were considering the matter chiefly in its relations to the E.M.F.s of cells under various conditions; and I think it yet remains to be recognised how far-reaching are the consequences of defective diffusion, and how many of the faults and shortcomings of the cells may be attributed to it. Rightly to comprehend the scope of its action, it is advisable to consider in some little detail just what takes place in the active materials of a cell when discharging at some rate sufficiently high to bring the effects of imperfect diffusion well into play; that is, at a rate which reduces its output considerably below what can be obtained at slower rates.

It is impossible to say the exact proportions in which the different parts of the active materials will contribute towards the discharge current on first closing the external circuit, for this largely depends on the relative resistances of the electrolyte and the active materials themselves—a very problematic question. Lead in a solid state has only about one-twelfth the conductivity of copper, and in the porous condition its specific resistance is almost certain to be very much higher, but even then it is no doubt con-

siderably less than that of the electrolyte; so, as regards the negative electrodes, the layers of active material nearest to the opposing positives will tend to supply more than their due share of the total current. On the other hand, although lead peroxide is one of the best conductors of electricity of any solid compound substance not entirely metallic, its specific resistance is of the order of a fluid electrolyte, and is probably higher than that of the ordinary acid solution in a cell; therefore, at the positive electrode it is possible that at first the inner layers of active material may discharge a little more rapidly than the others.

At both electrodes, however, the distribution of the work is also affected by other conditions, such as the nature and position of the conducting support; and, on the whole, it will be simpler and not much amiss to assume that the initial contribution of every molecule of active material to the discharge is approximately equal, provided that sufficient time has elapsed since the previous charge for the strength of the acid thoroughly to equalise itself throughout the pores.

But this state of affairs begins to alter immediately after the discharge has commenced. The diffusion not being sufficiently rapid to supply acid to all parts of the electrolyte as fast as it is being withdrawn by the active material, the solution becomes graduated into a series of layers or strata (assuming the active materials are of uniform porosity throughout) of different strengths; those layers directly adjacent to the surface undergoing practically no alteration, while the innermost layers will be the most weakened.

This change must necessarily be accompanied by a variation in the E.M.F.s acting at different parts of the active materials, for it has been demonstrated by several researches, notably those of Messrs. Gladstone and Hibbert and of F. Streintz, that the E.M.F. of a lead-lead peroxide couple in dilute sulphuric acid depends on the strength of the electrolyte. Roughly speaking, it slowly decreases from 2·05 volts in 1·200 acid to 1·85 volts in about 1·030 acid, and then drops away rapidly to 1·45 volt, the E.M.F. of the couple in pure water.

Consequent in its turn upon the variations in the E.M.F., the relative rates at which the molecules generate current are correspondingly affected throughout the active materials, [illegible] that means can a uniform potential difference be

maintained between every portion of the opposing electrodes. In this way, too, the inequalities in the strength of the electrolyte are prevented from passing certain limits, because just as fast as the acid in solution diminishes, so does the rate of sulphation which brings about this diminution decrease also; until at all points in the active material, the absorption of acid and its replenishment by diffusion just balance each other, the nett result being that the outer layers supply considerably more, and the inner layers considerably less, than their due share of the current.

This unequal distribution of the work is not only maintained throughout the discharge, but becomes more pronounced towards the end, for the conditions which regulate the rate of diffusion are steadily growing worse the whole time. The active materials gradually increase in bulk as they sulphate, thereby reducing their porosity, and it is just those portions through which the whole of the diffusion to the interior has to take place that choke up soonest and most thoroughly.

As the discharge proceeds, the E.M.F falls fastest where the sulphation is most rapid, and a more equitable proportion of the work would then be thrown onto the other parts of the active materials, were it not that their output is limited by the rate of diffusion, so they can only draw on the surrounding electrolyte till its strength and their E.M.F. is correspondingly reduced. Thus the potential difference between all parts of the opposing electrodes falls gradually and uniformly, and the variations of acid strength, small at first, slowly increase, until by the time the E.M.F. of the outermost layers working in the strongest acid has dropped to about 1·85 volt, solely by reason of their advanced state of discharge, the specific gravity of the solution round the inner layers will be 1·030 or thereabouts, and their E.M.F. also only about 1·85 volt, although they may not have done a tithe of the work of which they are capable.

At this stage the specific conductivity of the active materials becomes the chief factor in controlling the further course of the discharge. The resistance of the outer and most sulphated layers goes up rapidly, and for a short time the burden of the discharge is probably taken up by the layers immediately beneath them. These, however, soon follow suit, and the resistance of the inner layers of the

electrolyte from which by now almost the whole of the acid has been abstracted, also being very high, the potential difference between the electrodes very quickly drops below the normal limit.

It is now apparent why the output of a cell decreases so much on heavy discharges, and also why little or no increase of capacity can be obtained by using masses of active material of more than a certain thickness. The higher the rate of discharge or the more impeded the diffusion, the less is the interior of the active material drawn upon for the maintenance of the current; while if either of these conditions is pushed to an extreme, nearly the whole of the work is done by a very thin outside layer, and by the time this is exhausted hardly any acid will be left in the electrolyte surrounding the remainder. Of course, as soon as the discharge is stopped fresh acid begins to diffuse in, and after a little while a further discharge is obtainable. By repeating this proceeding a sufficient number of times, the larger proportion of the deficiency on the first discharge may be made up.

Recharging is seldom effected at such extremely high rates as are sometimes used for the discharge, but they must often be quite sufficient to liberate acid in the pores of the active material considerably faster than it can be dissipated; and, although in this case the effects of imperfect diffusion are not so evident and the details of the procedure which brings them about are still more complicated, yet, following the same line of reasoning as has just been applied to the discharge, certain general conclusions may be drawn.

The outer layers of active material will absorb more than their due proportion of the current, and by the time they are fully desulphated the inner layers, as yet only partially charged, will be surrounded by abnormally strong acid to enable them to maintain an equivalent voltage. Unless, therefore, the current is prolonged for a time after gassing has commenced and the end of the recharge only determined by a sufficiently high potential difference being attained, there is some likelihood of the inner layers not receiving their proper charge at all; and in any event the gassing, by expelling some of the electrolyte from the pores and destroying its continuity, must itself greatly retard the

Not only, then, is the *output* of a cell materially diminished through insufficient diffusion, but its *durability and life* must also be more or less seriously affected owing to the injurious conditions to which portions of the active materials and their metallic supports are thereby subjected: conditions favourable to the breaking up of the molecular structure of the former with "sulphating" and all its attendant evils, and to the destruction of the latter by local action. These effects are chiefly experienced by the innermost layers of active material which work in abnormally weak acid towards the end of the discharge and abnormally strong acid towards the end of the charge; and, in addition, do not undergo that thorough desulphation on charging necessary to help to bring them back to their normal state. The outermost layers also suffer however, inasmuch as they are liable to be over-discharged to the point of reversal every time the full output is required from the cell. At the positive electrodes, wherever the layer of peroxide in immediate contact with the support is broken up from any of the preceding causes, the metal itself will become exposed to electrolytic action and its sulphation and corrosion greatly facilitated.

A third effect of imperfect diffusion is to reduce the electrical efficiency of the cell. In part it acts by lowering the average E.M.F. of discharge and raising that of recharge, the missing electrical energy appearing as heat generated at the end of both processes, when the outside electrolyte diffuses in and mixes with that of unequal strength contained in the pores of the active materials. But when this takes place, the conditions of equilibrium previously existing as regards E.M.F. between all parts of the active material are disturbed; local currents flow, more heat results, and consequently the ampere-hours available on discharge are also somewhat diminished, and those necessary for recharge somewhat increased. The loss of energy due to these causes was pointed out and demonstrated by Messrs. Duncan and Wiegand in 1889. It follows, and is indeed found to be so in practice, that the best efficiency of a cell is obtained by commencing its discharge immediately the recharge is finished, and *vice versâ*. When the discharge rates are high or the diffusion poor, the difference may be considerable.

Undoubtedly the abnormal sulphation is the most serious result of impeded diffusion, for not only does it directly depreciate the electrodes and bring about a permanent reduction of their capacity in proportion to the quantity of active material affected; but also, by choking up the space available for the electrolyte, it aggravates the causes through which it was itself started, and so increases the temporary losses of capacity due to high discharge rates, besides reacting unfavourably on the cell's efficiency.

The only practical method of determining the extent to which diffusion into the pores of the active materials is provided for in a cell is to compare its outputs at different discharge rates. There have been cells on the market of the Faure type, and possibly are still, which show a steadily increasing capacity down to a thirty- or forty-hour rate. Such inadequate diffusion is due either to the masses and layers of active material being too thick, or to the free access of the electrolyte to their surfaces being too much impeded, or to their porosity being insufficient; often it is brought about by a combination of these causes. The two former conditions can easily be improved by proper mechanical design. To compensate for the latter special devices are sometimes employed, such as perforating the active materials, or providing channels through their interior or inclosed spaces in their midst to act as reservoirs of electrolyte; but the more usual plan has been to mix various substances, such as magnesium sulphate, salt, sugar, carbon, and so forth, with the lead compound used for pasting, and to remove them afterwards by solution or the action of the forming current.

Still, when all these precautions are taken they will not increase the diffusion beyond a certain degree. That this is so is shown by those commercial cells of Planté type, in which extremely thin layers of active material are employed with a very free access of electrolyte to their surfaces, for even these do not attain their maximum output at more than a twelve-hour discharge rate although there is very little diminution at about a nine-hour rate, but above this it falls off with increasing rapidity.

The fact is, to go to the root of the trouble, the *molecular porosity* of the active materials, whether of the Faure or *Planté* type, needs to be considerably increased. If an

ordinary active material prepared from a paste of litharge or red lead could be enormously magnified, it would be seen that the minute spaces between the individual grains are very caverns in comparison with those that penetrate the grains themselves, and it is these latter which appear to prevent the diffusion from proceeding at more than a certain rate, no matter how large the former may be. The total porosity of an active material is in itself therefore but a very partial guide as to its capabilities. For instance, its molecular pores might be almost stopped up with irreducible sulphate resulting from improper treatment during its first formation or afterwards, and yet it could possess a very open structure as judged by a microscopic examination or by the quantity of liquid it was capable of absorbing.

Devices such as those just now mentioned may, within limits, improve the total porosity of the active materials, but they leave their molecular porosity unaltered, for this depends almost entirely on the lead compound used as raw material, and is rigidly fixed by its chemical composition and specific gravity. The only exception is in the case I have already referred to, where the partial sulphation of dense materials, such as Pb, PbO or Pb_3O_4, at an intermediate stage of their first formation leads to growth and expansion and a consequent increase in their ultimate porosity.

The molecular porosity of active materials of the Planté type, and of all those of the Faure type prepared from litharge or minium, is probably only about 25 per cent., and can hardly exceed 40 per cent., even assuming that a very heavy preliminary sulphation takes place. A more porous material is obtained by the electrolytic reduction of lead chloride which has had a small proportion of zinc chloride fused with it. The two form a molecular compound that sets to a crystalline mass of low specific gravity; and when the zinc chloride and the chlorine of the lead chloride have been removed, *every molecule* of the lead remaining is surrounded by a space of about twice its own size. It possesses therefore a true molecular porosity of 65 to 70 per cent., and is capable of holding about two-thirds of its own apparent volume or twice its actual volume of electrolyte.

This active material perfectly fulfils the proper conditions

as regards the quality of its structure, but as regards the degree of porosity it is only a step in the right direction. *In the ideal active material every one of its molecules should be surrounded by space sufficient to hold enough electrolyte for its complete discharge, so that no diffusion has to take place either from outside or between different parts of the active material itself.* To achieve this result it must be able to contain not merely twice, but ten to twenty times its actual bulk of electrolyte, corresponding to a molecular porosity of 90 to 95 per cent.

It is of course one thing to indicate the ideal conditions, and quite another to show how they are to be attained. The problem is to prepare an active material possessed of an extremely high molecular porosity without too much reducing its cohesion and mechanical strength generally. There are, at any rate, no fundamental difficulties in the way. Many substances exist, such for example as carbon in the form of charcoal, which prove that porosity and strength can go together. A remarkable instance is furnished by "block magnesia," a basic magnesic carbonate, which has a 90 to 95 per cent. porosity and can take up about nineteen-twentieths of its own nominal volume of liquid, and yet will withstand a crushing strain of more than 80 lbs. per square inch.

Given an active material with similar qualities, practically the full theoretical output corresponding to a 50 per cent. sulphation could, I believe, always be obtained from a cell, no matter how high the rate at which it were discharged. But what is of still more importance, the durability of the cell should be immensely increased and its life proportionately lengthened, and most of the causes that give rise to abnormal sulphation being eliminated, there would be little permanent loss of capacity or electrical depreciation. Then, too, an exceedingly high electrical efficiency should be realised, for the dissipation of energy in the form of heat would be reduced to an almost negligible quantity.

If all these improvements are possible, there is yet hope that lead cells may eventually fill their unique position as the sole practical means of storing electrical energy, far more adequately than they have hitherto done; but whether 'o this comes about, I feel assured that no substantial

advance remains to be effected except in the direction I have indicated, and the only other alternative will be to introduce a new combination altogether.

PART II.

In the first part of this paper I have said that the utility of the lead—sulphuric acid—lead peroxide combination appears to be due to the insolubility of the active material of both electrodes under all normal conditions of treatment. This is not, however, the whole matter, for essential as the insolubility of the compounds may be to success, it would probably be insufficient were it not in conjunction with certain properties which are inherent in lead and its compounds and form one of their most marked chemical characteristics.

Lead, like all the metallic elements, unites with other elements and radicles to form normal compounds and salts of a perfectly definite composition, such as the monoxide, peroxide, sulphate, and so forth. It also enters with greater ease than most of the metals into more complex combinations to produce "basic salts" (sometimes termed "sub-salts"), in which it is partly combined with O or HO, as an oxide or hydrate, and partly with some other element or radicle. Usually it is capable of producing not merely one, but a whole series of basic salts with each radicle; of which the basic chlorides, nitrates, and acetates are well-known examples. In addition to this, it is almost unique amongst the metals in the facility with which it combines with two or more different radicles, other than O or HO, and gives rise to curious compound salts such as—

"Lanarkite," $Pb_2\begin{cases}SO_4\\CO_3\end{cases}$ "Leadhillite," $Pb_4\begin{cases}SO_4\\(CO_3)_3\end{cases}$

"Phosgenite," $Pb_2\begin{cases}Cl_2\\CO_3\end{cases}$ Lead Chlorosulphide, $Pb_2\begin{cases}Cl_2\\S\end{cases}$

But besides all its normal, basic, and poly-acid salts and compounds, lead will, under suitable conditions, form others which cannot accurately be represented by any formula at all. The two most important commercial preparations of

lead, namely white lead and red lead or minium, both furnish well-marked examples of this behaviour.

The first of these is a basic lead carbonate whose average composition when prepared by the old "Dutch" process is generally represented by the formula $2PbCO_3$, $Pb(HO)_2$, or $Pb_3(CO_3)_2(HO)_2$; but this is purely an approximation, as the relative proportions of carbonate and hydrate are found to vary very appreciably in different samples, even if produced under practically identical conditions. By other processes, especially precipitation methods, any number of basic carbonates of indefinite composition may be obtained, in which the proportions of CO_3 and HO vary over a much wider range, and show very little preference for uniting in any simple ratio such as is expressed by the formula just given.

Minium also has no fixed or definite chemical composition. Under the action of reagents it behaves as if it were composed of lead monoxide and lead peroxide, and the formula $2PbO$, PbO_2, or Pb_3O_4, most nearly represents its average composition; but samples fully possessed of the fine scarlet colour, its distinctive physical property, have been found to approximate more closely to Pb_6O_7, Pb_4O_5, Pb_2O_3, or to some other degree of oxidisation between these simpler ratios.

Now Mendelejeff has ascribed some of the peculiarities of lead and its compounds (as also of boron, silicon, and other inorganic elements) to their "polymerisation." That is to say, he assumes that the molecule of lead may sometimes consist of a large but undetermined number of atoms, Pb_x; while, in the same way, the molecule of lead monoxide is not necessarily composed of one atom of lead and one of oxygen, PbO, but of many multiples of these quantities, Pb_xO_x: so also lead peroxide may be Pb_xO_{2x} and so on. The assumption does not, of course, affect the percentage composition of the lead compounds as ascertained by analysis, but only their molecular weights, and these cannot be directly determined.

This theory is partly based upon and affords a simple explanation of the readiness of lead to form the basic and poly-acid salts just referred to. Some of the atoms of lead in the complex molecule combine with one radicle and with another; and if, purely for the purposes of

illustration, we suppose that there are twelve atoms of lead present, or that the molecule of lead monoxide from which they are derived has a composition $Pb_{12}O_{12}$, some of them may be expressed in the following formulæ:—

Basic hydrates—$Pb_{12}\begin{cases} O_8 \\ (OH)_8 \end{cases}$ $Pb_{12}\begin{cases} O_6 \\ (OH)_{12} \end{cases}$

Basic chlorides—$Pb_{12}\begin{cases} O_6 \\ Cl_{12} \end{cases}$ $Pb_{12}\begin{cases} O_8 \\ Cl_8 \end{cases}$ $Pb_{12}\begin{cases} O_6 \\ (OH)_6 \\ Cl_6 \end{cases}$

Basic carbonates—$Pb_{12}\begin{cases} (CO_3)_6 \\ (OH)_{12} \end{cases}$ $Pb_{12}\begin{cases} (CO_3)_8 \\ (OH)_8 \end{cases}$

Sulpho-carbonates—$Pb_{12}\begin{cases} (SO_4)_6 \\ (CO_3)_6 \end{cases}$ $Pb_{12}\begin{cases} (SO_4)_3 \\ (CO_3)_9 \end{cases}$

But the theory also equally well explains the real nature of the lead compounds of variable and indefinite composition. Their behaviour has always seemed somewhat puzzling, and they were generally regarded as not being chemical compounds at all: merely intimate mixtures of other and simpler compounds. Thus, white lead was a mixture in varying proportions either of normal lead carbonate and lead hydrate, or of some definite basic carbonate with an excess of normal carbonate.

$$2PbCO_3 + Pb(HO)_2 = Pb_2(CO_3)(HO)_2 + PbCO_3$$

Red lead was a mixture of lead monoxide with lead peroxide, or possibly of lead sesquioxide with an excess of monoxide.

$$Pb_3O_4 = 2PbO + PbO_2 = Pb_2O_3 + PbO.$$

It will be evident, however, that we have only to assume a sufficiently complex molecular structure, and any number of true compounds between lead and a given set of radicles become theoretically possible: compounds of such closely allied composition that their physical and chemical properties grade imperceptibly from each one to the next and so defy isolation. No doubt in many instances the whole series of compounds will be so unstable and so easily resolved into their proximate components, that chemically

they do appear to be nothing more than mixtures of them. In other cases only the combinations in simple ratios may possess much stability; but in every case the latter will probably be somewhat more stable and more readily formed than the remainder, which need suitable conditions for their production.

The manufacture of red lead furnishes a good example of the application of the theory, and a suggestive instance of the way in which a series of compounds is brought about and of the relationship of its various terms to each other. The further oxidation of litharge by roasting at a temperature not so high as that required for its own formation, does not appear to consist in the conversion of successive molecules of PbO direct to Pb_3O_4, or some other definite oxide, but in the gradual absorption of oxygen by each molecule, which takes it up, atom by atom, and passes through a whole series of oxides of gradually increasing richness, the action proceeding more or less simultaneously and uniformly at all parts of the mass, according to the relative adequacy of the air supply. Again supposing the constitution of the monoxide to be $Pb_{12}O_{12}$, the series of compounds obtained may be represented as follows; but fully to account for the observed facts, its molecular composition would have to be far more complex, so as to provide numerous other oxides between each of the terms shown:—

$Pb_{12}O_{12}$	12PbO	PbO
$Pb_{12}O_{13}$	$11PbO + PbO_2$	—
$Pb_{12}O_{14}$	$10PbO + 2PbO_2$	Pb_6O_7
$Pb_{12}O_{15}$	$9PbO + 3PbO_2$	Pb_4O_5
$Pb_{12}O_{16}$	$8PbO + 4PbO_2$	Pb_3O_4
$Pb_{12}O_{17}$	$7PbO + 5PbO_2$	—
$Pb_{12}O_{18}$	$6PbO + 6PbO_2$	Pb_2O_3

The first column gives the assumed molecular composition of the oxides; the second expresses it in terms of separate molecules of monoxide and peroxide as they would appear under analysis; and the third merely shows the simplest proportional composition. Most commercial minium comes somewhere between Pb_4O_5 and Pb_3O_4, prolonged roasting generally being required to bring it quite up to the latter

proportions; but as samples are occasionally found to be still further oxidised, the series is extended to the sesquioxide, Pb_2O_3. Here or hereabouts, the extreme limit to which the oxidation can be pushed by roasting is reached, because the temperature necessary to carry it to this stage is nearly as high as that at which the deoxidation of the sesquioxide by heating commences. The two opposing tendencies balance each other, and the absorption of oxygen then comes to an end.

I now propose to make use of this "polymerisation" theory in dealing with the various phenomena observed in lead cells, for it enables us to reconcile their physical and chemical aspects, and to give a more consistent and satisfactory account of the changes taking place, than can otherwise be done; and it is with a view to making the application of the theory as clear as possible that I have felt it advisable to set out the foregoing considerations regarding the lead compounds in general and minium in particular at such length.

In the first place, I assume that the fully formed active materials, electrolytically prepared at both electrodes, are not Pb and PbO_2, but Pb_x and Pb_xO_{2x}; that is, they are allotropic or polymeric modifications; or they have a complex molecular structure—whichever term or phrase we please.

On closing the external circuit, the molecules of lead at the negative begin to combine with SO_4 from the electrolyte; not, however, breaking up into independent molecules of normal lead sulphate, $PbSO_4$, round a nucleus of uncombined metal; but the molecules as a whole, taking part in the combination, and, as the discharge proceeds, passing through a continually changing series of sub-sulphates, without any rupture of their molecular complexity.

At the positive, the reactions, though different, take place in an exactly similar manner. Oxygen is gradually abstracted and SO_4 substituted in its place, a sequence of compounds of sulphate and peroxide being produced. Still keeping to our imaginary twelve atoms of lead to the molecule, these two series of compounds may be represented as follows:—

Pb_{12}	$Pb_{12}(O_2)_{12}$
$Pb_{12}(SO_4)$	$Pb_{12}(O_2)_{11}(SO_4)$
$Pb_{12}(SO_4)_2$	$Pb_{12}(O_2)_{10}(SO_4)_2$
$Pb_{12}(SO_4)_3$	$Pb_{12}(O_2)_9(SO_4)_3$
$Pb_{12}(SO_4)_4$	$Pb_{12}(O_2)_8(SO_4)_4$
$Pb_{12}(SO_4)_5$	$Pb_{12}(O_2)_7(SO_4)_5$
$Pb_{12}(SO_4)_6$	$Pb_{12}(O_2)_6(SO_4)_6$

But neither of these series is continued until the active material is fully sulphated and the compound $Pb_{12}(SO_4)_{12}$ reached. Just as the oxidation of litharge by roasting is necessarily arrested at some stage before it is fully converted into peroxide, so here a limit is presently attained; and a little consideration will show that some such limit is not merely probable but inevitable, and that a direct cause, partly physical, partly chemical, can be assigned for it.

We know that both lead and lead peroxide possess a very considerable electrical conductivity; but that, on the other hand, pure lead sulphate is practically a non-conductor. Both the negative and positive active materials must therefore undergo a great change of resistance in the course of their sulphation; a change either spread more or less uniformly over the whole discharge, or else occurring abruptly at some special stage. The latter appears to be what really happens, for although our information regarding the changes of resistance in lead cells is extremely vague and meagre, we know that there is not much variation throughout the main portion of the discharge, but that the resistance begins to rise considerably towards the end. The exact point of change is immaterial to the present argument, but I believe that when the active materials approach a proportional composition Pb_2SO_4 and $Pb_2O_2SO_4$ respectively, the rate of increase of their resistance experiences a rapid acceleration, and their resistance itself goes up enormously. The fact of importance is that wherever and whenever such a change of resistance takes place, it must necessarily terminate the discharge and bring about all the phenomena which do occur.

Just as fast as the resistance of the active materials, and therefore the internal resistance of the cell, rises, the potential difference at its terminals will fall away; and by the time the internal resistance has become very large in proportion to that of the external circuit, the potential difference will be

reduced practically to zero. Or, to put it another way, just as fast as the resistance of the active materials rises, more and more of the electrical energy they would otherwise liberate is expended, so to speak, in their own molecules, until, when the rest of the resistances in circuit become relatively negligible, equilibrium is nearly established and the liberation of energy almost ceases. This is why it is impossible to push the discharge of a cell further even by short-circuiting it ; and yet on breaking the circuit, *i.e.*, increasing the external resistance to infinity, the E.M.F. rapidly rises to nearly its original value, thereby showing that the chemical affinities are neither exhausted nor saturated.

The aggregate results of the chemical changes at each electrode during a complete discharge are expressed in their simplest terms in the following equations :—

At the negative :—

$$\left\{ \begin{matrix} Pb \\ Pb \end{matrix} \right\} + SO_4 = \left\{ \begin{matrix} PbSO_4 \\ Pb \end{matrix} \right\}$$

At the positive :—

$$\left\{ \begin{matrix} PbO_2 \\ PbO_2 \end{matrix} \right\} + H_2 + H_2SO_4 = \left\{ \begin{matrix} PbO_2 \\ PbSO_4 \end{matrix} \right\} + 2H_2O.$$

But augment the E.M.F. of the discharged cell ever so slightly from an outside source, and the point of equilibrium is passed ; the active materials begin to absorb energy instead of liberating it, and incipient reversal commences. In fact, in primary battery language, the cell has polarised ; but unlike other cells, at both electrodes. (I am here assuming that the negative and positive electrodes contain equivalent amounts of active material, and both discharge under such equal conditions as regards maintenance of acid supply in their pores, etc., that they polarise or reverse at the same time.)

If the applied E.M.F. is sufficient to maintain a current through the cell, a kind of double reaction now goes on at both electrodes. At the negative, the lead still continues to sulphate ; but, at the same time, the sulphate already there begins to peroxidise : at the positive, the peroxide still undergoes reduction to sulphate ; but, at the same time, *the sulphate* already there further reduces to

lead. Although the preceding statement probably gives a better idea of the real nature of the changes taking place, we may also put it more simply and say, as regards the nett results only, that on the one side lead is directly peroxidised, and on the other side peroxide is directly reduced to metal, the proportion of sulphate in both cases remaining constant throughout. These reactions will continue until all the lead is peroxidised and all the peroxide reduced; and the two series of compounds through which the active materials may be supposed to pass are given below, commencing with the two last terms of the previous series, which represented their composition at the end of a complete discharge.

$Pb_{12}(SO_4)_6$	$Pb_{12}(O_2)_6(SO_4)_6$
$Pb_{12}(O_2)(SO_4)_6$	$Pb_{12}(O_2)_5(SO_4)_6$
$Pb_{12}(O_2)_2(SO_4)_6$	$Pb_{12}(O_2)_4(SO_4)_6$
$Pb_{12}(O_2)_3(SO_4)_6$	$Pb_{12}(O_2)_3(SO_4)_6$
$Pb_{12}(O_2)_4(SO_4)_6$	$Pb_{12}(O_2)^2(SO_4)_6$
$Pb_{12}(O_2)_5(SO_4)_6$	$Pb_{12}(O_2)_2(SO_4)_6$
$Pb_{12}(O_2)_6(SO_4)_6$	$Pb_{12}(SO_4)_6$

In this way the composition of the two active materials is exactly transposed without the proportions of sulphate present being further increased. At the same time their molecular structure is maintained throughout the reversal, so that, although the internal resistance is far higher than at any period during the discharge or recharge, the conductivity of the active materials is never really interrupted.

The following equations give the sum of the reactions during a complete reversal in their simplest terms.

At the negative :—

$$\left\{\begin{matrix} PbSO_4 \\ Pb \end{matrix}\right\} + \begin{matrix} SO_4 \\ SO_4 \end{matrix} + 2H_2O = \left\{\begin{matrix} PbO_2 \\ PbSO_4 \end{matrix}\right\} + 2H_2SO_4$$

At the positive :—

$$\left\{\begin{matrix} PbO_2 \\ PbSO_4 \end{matrix}\right\} + \begin{matrix} H_2 \\ H_2 \end{matrix} + H_2SO_4 = \left\{\begin{matrix} PbSO_4 \\ Pb \end{matrix}\right\} + \begin{matrix} 2H_2O \\ H_2SO_4 \end{matrix}$$

The symbols are arranged in double lines to indicate the probable dual nature of the reactions to which I have just referred.

As soon as all the lead has been oxidised at the one electrode and all the peroxide reduced at the other, the reversal is finished, and the back E.M.F. of the cell rises rapidly; but as, at the same time, the proportion of sulphate begins to diminish in both active materials, their internal resistance falls with equal suddenness, and the end of the reversal is consequently not marked by so much increase in the potential difference required to maintain the flow of current as might be expected.

The next stage is equivalent to the recharge of a cell which ordinarily follows on a discharge, except that the direction of the current and the composition of the two active materials are reversed; but in either case the reactions are exactly the same, and consist in the gradual abstraction of sulphate from both active materials until they are finally brought back to lead and lead peroxide, just as they existed at the commencement of the discharge.

The series of compounds through which this is effected will be similar to those of discharge, but now occurring in the converse order, and they are shown as the last stage of the two series given on the next page. These represent the whole of the changes experienced by the active materials during their passage through a complete cycle consisting of discharge, reversal, and recharge; or, by passing from the one series to the other along the diagonal lines connecting similar terms in the two series, the more usual cycle of discharge and recharge only.

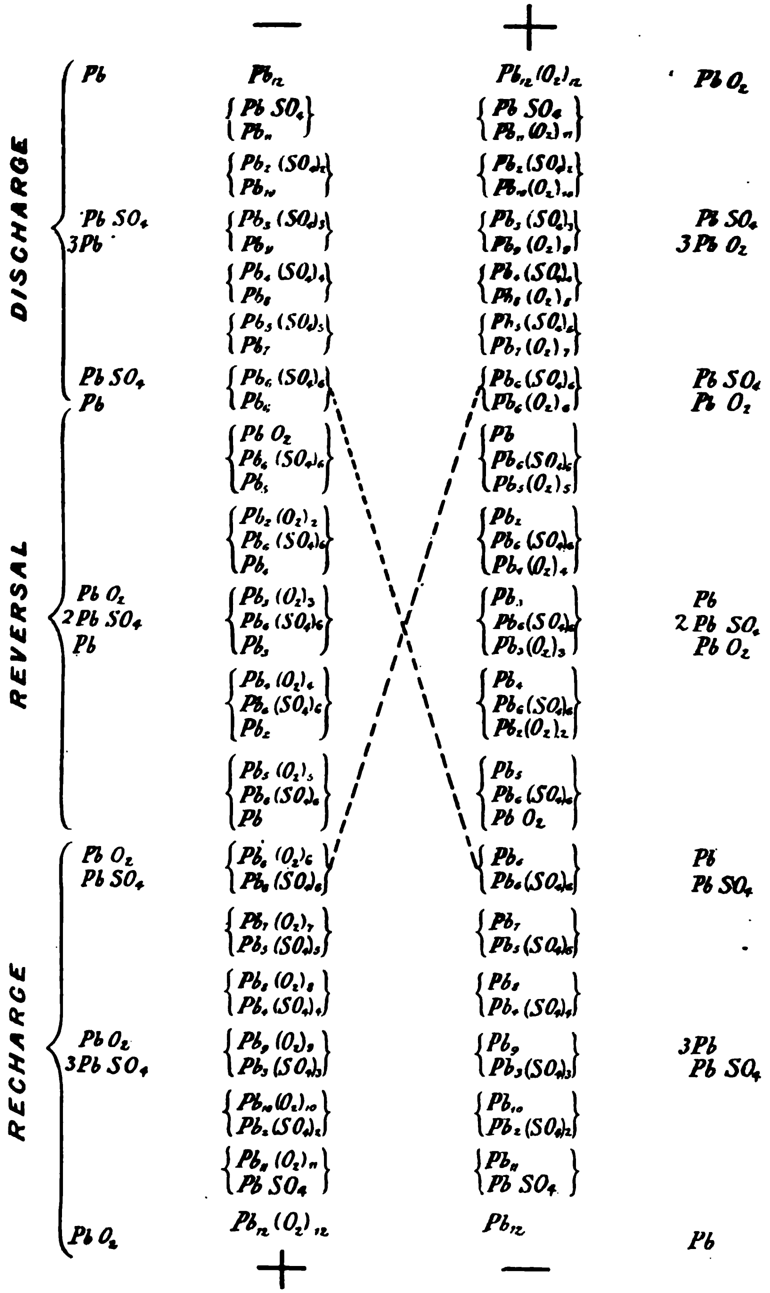
The hypothetical molecules containing twelve atoms of lead are still presumed, and the terms in the first two stages —discharge and reversal—are, of course, the same as those already given, but with the chemical symbols now arranged slightly differently.

The formulæ on either side show the simplest proportional composition of the active materials, as they would appear under analysis, at some of the intermediate points.

The total effects of the recharge, expressed in their simplest terms, are as follows:

At the negative:—

$$\left\{\begin{matrix} PbSO_4 \\ Pb \end{matrix}\right\} + H_2 = \left\{\begin{matrix} Pb \\ Pb \end{matrix}\right\} + H_2SO_4.$$


—
+
DISCHARGE
REVERSAL
RECHARGE
Pb
Pb SO4
3Pb
Pb SO4
Pb
Pb O2
2 Pb SO4
Pb
Pb O2
Pb SO4
Pb O2
3Pb SO4
Pb O2
Pb12
Pb12 (O2)12
Pb O2
Pb SO4
3 Pb O2
Pb SO4
Pb O2
Pb
2 Pb SO4
Pb O2
Pb
Pb SO4
3Pb
Pb SO4
Pb
Pb12 (O2)12
Pb12
+
—

At the positive :—

$$\begin{Bmatrix} PbSO_4 \\ PbO_2 \end{Bmatrix} + SO_4 + 2H_2O = \begin{Bmatrix} PbO_2 \\ PbO_2 \end{Bmatrix} + 2H_2SO_4$$

To make the account of the charging reactions complete, it would be necessary to consider the production of persulphuric acid, $H_2(SO_4)_2$, the exact constitution of the lead peroxide when thoroughly desulphated, and, closely connected with these, the abnormally high E.M.F. obtained towards the end of the charge and the first few minutes of discharge; but as they are none of them directly related to the main reactions, I do not propose to deal with them here.

Probably of all the phenomena observed in storage cells, the least studied, but the most interesting and important theoretically, are those of reversal. Quite apart, indeed, from their direct bearings on storage battery problems, the electrolytic conversion of electro-positive lead into electro-negative lead peroxide and *vice versâ*, and the molecular mechanism by means of which these results are effected well deserve further study for the light it may throw on the relationship between the chemical and electrical forms of energy as well as on other problems of chemical physics.

I cannot recall ever having seen any definite chemical theory of reversal propounded, but believe the general idea is—it certainly was mine for a long time—that at both electrodes the active materials have to be fully converted into lead sulphate before they can undergo further oxidisation or reduction. Indeed, if the usual explanations of the discharge reactions are adapted this seems to be the only possible procedure, but one which at the same time brings out most strikingly the discrepancies between fact and theory. The view, no doubt, appears to derive support from the very evident "sulphating" that so frequently accompanies the reversal of electrodes, and may, if they contain large masses of active material, lead to their entire disintegration in its endeavours to make room for itself; but this is due to excessive local action, as will be explained later. On the other hand, any type of electrode in which the active material is distributed in thin layers may be reversed *without showing* the slightest trace of sulphate

throughout the operation or suffering any loss of capacity provided a sufficiently heavy current is maintained.

Fortunately one piece of evidence exists which, to my mind, lends strong confirmation to the views I have put forward as to the real nature of the reactions of reversal, and that is the appearance of lead peroxide on the surface of the negative active material towards the end of its complete discharge; but although the fact has frequently been cited in explanation of the rapid fall of voltage, I do not think its full significance has hitherto been realised. As Mr. Swinburne once pointed out, it seems almost impossible to suppose that the peroxide can be produced by the cell's own unaided energy, and no doubt in practice it is brought about by a reinforcement of its potential difference from other cells in series with it and not so fully discharged. However this may be, it does not affect the value of the observation itself, which lies in showing that the formation of peroxide sets in before the active material is fully sulphated and in indicating how the reversal commences. I am not aware that uncombined lead has ever been detected in the active material of an exhausted positive; but given a cell whose negatives have the larger capacity so as to ensure the positives being thoroughly run down, and I think some indications of it might be found if discharged under suitable conditions. More probably though, no test can be devised to which the metal will respond with the same ease as its peroxide, and before it is re-oxidised by local action.

With regard to the assumption I have made earlier in the paper that the proportional composition of the active materials at the stage where their resistance rises so rapidly as to terminate the discharge and bring about the reversal, is Pb, $PbSO_4$ and PbO_2, $PbSO_4$ respectively, my chief corroboration, so far as direct analysis is concerned, comes from Mr. Robertson's analysis of positive active material given in Professor Ayrton's paper of 1890. He found that the sediment from the positives, and the discharged positive active material itself, both approximated in composition to the second of the two formulæ just mentioned. Unfortunately, neither there or anywhere else that I know of are quantitative data given as to the composition of discharged negative active material, but I have repeatedly found that *Planté type* electrodes, properly reversed, afford just the

same output whether positives or negatives; so that if the one formula is accepted the other should hold good also.

Of course the percentage of sulphate present in the discharged active material tells nothing, and is only misleading unless account is also taken of the sulphate there at the commencement of the discharge. In the case quoted above, the fully charged active material was found to be quite free from sulphate, but this is unusual even for new electrodes, and most exceptional for those which have been in use for any length of time; consequently in many instances the percentage of sulphate in the active materials when discharged considerably exceeds that required by the formula.

A more practical confirmation based on the general experience of a large number of people, is supplied by the specific capacity of the active materials. Although only with difficulty, outputs very nearly as high as 50 and 60 ampere-hours per pound of active material have been and can be obtained, corresponding to close upon 50 per cent sulphation; but never, I believe, under any conditions whatever, have these figures been exceeded.

It is well known that towards the end of a discharge, the curve of the potential difference of a cell varies considerably in character according as the negative or positive electrodes have the smaller capacity and are the first to give out; dropping off with extreme suddenness in the former case, and more gradually, although still with considerable rapidity, in the latter case. Now if, as I maintain, the potential difference at this stage is chiefly controlled by changes going on in the conductivity of the active materials, then the lack of conformity between the two curves must connote a corresponding variation in the way the resistance of the two active materials rises. At the negative, the increase is sudden and large, putting a very definite limit beyond which further sulphation is impossible and reversal commences; and analogy with the sub-oxides of lead suggests that this is most likely to occur when a composition Pb_2SO_4, corresponding to Pb_2O, is attained. At the positive the rise in resistance takes place more slowly, and although soon sufficient to bring the potential difference down to the point at which the discharge is usually stopped,

yet, if it is allowed to continue, the sulphation is able to proceed some stages further with a steadily falling voltage. Here again analogy with the oxides of lead points to the change commencing at the composition PbO_2, $PbSO_4$ corresponding to the sesquioxide PbO_2, PbO, and augmenting gradually as the composition of the active material approaches to PbO_2, $2PbSO_4$ corresponding to red lead PbO_2, 2PbO.

We have now examined the *normal* constitution of the active materials under all conditions of use, and I have endeavoured to show by the aid of the hypothesis of polymerisation how at every stage, except when fully charged, it consists of true compounds of lead sulphate with lead or lead peroxide; or, during the period of reversal, with both at the same time. Yet no direct chemical evidence can be adduced as to the existence of any one of these compounds, with the possible exception of Dr. Frankland's "brown salt," PbO_2, $2PbSO_4$, which he believes he isolated in 1889, and even in this instance Messrs. Gladstone and Tribe were unable to confirm his results. To all chemical tests, the active materials behave merely as mixtures containing normal lead sulphate in various proportions, but the lack of corroboration in this direction was only to be expected by analogy with red lead, white lead and similar compounds, and it only serves to show the degree of their instability.

Unfortunately there is other most troublesome evidence as to the extreme feebleness of the compounds now in question: not only do they break up under all chemical tests outside the cell, but even in the cell itself they act similarly under many conditions that cannot in practice always be avoided, and herein we have the origin of "sulphating," and the source of most of the infirmities which so largely limit the life and commercial usefulness of lead cells. On the slightest provocation, the molecules of active material forsake their allotropic or polymeric structure and are resolved into what, from a general chemical standpoint, would be called a more normal state, but one which in its special relationship to storage cells I shall here term abnormal. Each complex molecule splits up into a number of simpler ones, some of normal sulphate and others of lead or lead peroxide. Taking for example the composition of the fully discharged

active materials as represented by the two terms previously given, these would break up as follows:—

$$Pb_{12}(SO_4)_6 = 6Pb + 6PbSO_4$$
$$Pb_{12}(O_2)_6(SO_4)_6 = 6PbO_2 + 6PbSO_4.$$

Such a change easily accounts for all the effects characteristic of "sulphating." The rearrangement of structure can hardly be accomplished without producing some alteration in the bulk of the active materials; and it is most probable that the independent molecules of sulphate will require more room than when in a combined state. A strain is thus put on the active materials which tends to reduce their porosity generally, while at the parts where the sulphation actually occurs the pores will be almost blocked up. If it is more than can be relieved by mere compression of the active materials, their disintegration will commence; and if the sulphation is excessive, the effect extends to the support, which either expands, buckles, or bursts asunder according to its construction and the amount of the strain experienced.

It is difficult to suppose that the free molecules of Pb and PbO_2 can themselves long escape sulphation, and so visible patches of white non-conductive irreducible sulphate soon make their appearance. Other known results such as reduction of capacity follow obviously, and need not be dwelt upon.

Prolonged contact with the acid electrolyte appears to be quite sufficient in itself to cause the active materials to pass over to this abnormal state; but in all probability the result is largely dependent on the percentage of sulphate they contain and only becomes acute after a certain stage is reached, for in practice cells left on open circuit are found to sulphate more or less according to the extent to which they have previously been discharged.

Fully charged active materials maintain their normal condition with considerable tenacity, but it is quite possible that the very gradual loss of capacity so often experienced by negative electrodes, and for which no satisfactory explanation has yet been offered, may be due to a change of molecular structure. The effect is generally accompanied by shrinkage of the active material, and in this connection it is somewhat *significant* to note that Schutzenberger's

allotropic form of copper was found to revert to its more usual state after prolonged immersion in dilute sulphuric acid, this change also being accompanied by shrinkage.

Although the instability of the active materials is inherent in their very nature and its results cannot be always or entirely avoided under any practical working conditions, yet much of the trouble is usually brought about by minor causes, some of which at any rate are preventible. Local action due to impurities in the electrodes or electrolyte, or to the presence of active oxygen in the form of persulphuric acid or hydrogen peroxide, or to excessive strength of acid, is one of the most frequent. The active materials, especially if fully charged or nearly so, are probably first partially sulphated just as when discharging, and so disposed to break up in the usual way; but the local action may also have a directly disruptive effect upon their molecular constitution as the proportion of sulphate increases. The most marked effects of local action, however, are experienced during the period of reversal, for not only do the molecules of active material then contain their maximum of sulphate, but both lead and lead peroxide at the same time, and a condition of far greater instability results even than on complete discharge. If the current is stopped during this stage, local action and sulphating proceed with great rapidity, and they are not entirely checked when the current is flowing unless it is of very considerable strength. On this account it is impossible properly to reverse many types of electrodes, for, owing to the very high resistance of the active materials throughout the process, the current is most unequally distributed and only a small fraction penetrates the portions not quite close to the support. Excessive local action ensues, and even if the electrodes are not rendered useless, the active materials will be choked with large percentages of sulphate, which it is impossible to reduce afterwards.

Another cause which no doubt plays a considerable part in breaking down the normal constitution of the active materials, is undue weakness of the electrolyte. This condition seldom exists in the bulk of the solution, but, owing to imperfect diffusion, as is fully explained in the first part of this paper, is frequently realised during discharge by the *portion* contained in the pores of the active materials. Most

probably, as soon as the percentage of acid present falls below a certain limit, incomplete sulphation occurs, and compounds containing lead monoxide or hydrated monoxide, $Pb(HO)_2$, are then produced; and the variations in the specific gravity of the electrolyte during discharge sometimes agree best with a reaction of this nature. Distinct evidence, indeed, has frequently been obtained of the presence of monoxide in discharged positive active material, and upon this has been based an oxidation theory of the cell reactions, which assumes that, at the positive at any rate, the formation of sulphate is only an incidental result, contributing nothing to the E.M.F., and being, in amount, no function of the output.

I prefer, however, to adopt the explanation I have suggested above, and consider that whenever indications of imperfect sulphation are observed they do not show the double sulphation theory to be at fault, but rather point to defective working conditions which prevent the proper and normal reaction from taking place.

Dr. H. E. ARMSTRONG: I think that the Institution of Electrical Engineers is greatly to be congratulated on having received so valuable a paper on so important a subject. Mr. Wade has stated his case with a clearness which is altogether unusual in dealing with matters of this kind; and his arguments are throughout logical and reasonable, and stated in a language to which one cannot object from any ordinary point of view. One may not share all his opinions, but throughout he argues his case in such a way that we cannot in the slightest degree take objection to the manner in which he states it. Dr. Armstrong.

Mr. Wade first discusses the nature of the changes which go on in the accumulator. We have worked at this subject in the Chemical Department at the Central Technical College for ten years past, and the analyses which Professor Ayrton and his colleagues communicated to this Institution in 1890 were carried out by Mr. Robertson in my laboratory. Ever since then I have felt that the cell offers a great many problems for study, both to the chemist and the electrician. This evening we are embarking on a new period, and may congratulate ourselves on having at last made some slight advance in the treatment of the problem. Mr. Wade puts forward, in the first instance, the conventional idea that we deal, on the one hand with lead, and on the other with lead peroxide. During the discharge these are converted into sulphates on both sides, and on re-charging we obtain a reversion again. Although that simple equation expresses the final result, probably a very great deal happens in between. We are not at all in a position at *the present time*, however, to say what it is that thus

Dr. Armstrong.

happens in the electrolysis of lead salts in sulphuric acid solutions. The phenomena we have to deal with in this case are undoubtedly complicated. Although many years have elapsed since Faraday electrolysed sulphuric acid, we practically know very little more now than we did when he ceased working at the subject. It is astonishing how very little advance has been made, notwithstanding the extraordinary importance that attaches to the subject. It is certain, however, that electrolysis of sulphuric acid does not take place in the simple way which is ordinarily assumed. There are a variety of explanations, which I will not enter into now, but probably there are many products evolved which play an important part in the case of the accumulator, but which have received very little attention; and I think the author has scarcely sufficiently noted the possibility of changes which take place in the electrolyte and which affect sulphation. On the other hand, the problem of the electrolysis of lead salts is a very difficult one. We do not in the least understand how the lead peroxide is formed from the sulphate. Its production is a peculiar phenomenon. Many lead salts cannot be electrolysed without peroxide being formed; that is to say, when you pass the current though a lead solution you get peroxide on the anode, and the whole of the lead cannot therefore be obtained in the metallic state on the cathode. On the other hand, there are solutions from which you can get the whole of the lead as lead, without any trace of peroxide being formed. I have been working at the subject for the last two years, and I cannot get any clue as to what determines the formation of peroxide, in some cases, and the production of lead and of lead only in others. I refer to these matters in order to emphasise the fact that there is much to be learned yet with regard to what happens both to sulphuric acid and to these lead compounds on electrolysis. But, after all, that does not greatly affect Mr. Wade's point. He attaches importance to the kind of lead compound which is formed, and has put forward a theory which is a perfectly rational one in its way—that you are never dealing with lead peroxide alone or with lead sulphate alone, but that you are dealing with a more complex substance which contains both those constituents. He thinks that is the explanation of the conductivity of the material in the cell as compared with the want of conductivity which is shown by lead sulphate. No doubt a great deal may be said for this theory, but I would call attention to a paragraph in Mr. Wade's paper where he says: "Unfortunately there is other most troublesome evidence as to the extreme feebleness of the compounds now in question." I am inclined to think that, except in one practical point, he does not help himself very much by assuming the existence of these compounds, as, if they exist at all, they are excessively unstable substances. He has, however, put forward a theory which enables us to understand why it is that only about half the peroxide present in the material is available. That result was established by Professor Ayrton and his colleagues through their examination of plugs taken from plates which had been treated in various ways. Whether it is good as theory or not, it is good as fact, for undoubtedly you cannot get much beyond that point. My only object in speaking about that fact is to say that although Mr. Wade's

Dr. Armstrong.

case is a reasonable one, I do not think there is very much in it.[1] I venture to think that the important part of Mr. Wade's paper is the latter portion, in which he discusses the character of structure that is necessary in order to ensure the maximum rate of discharge and charge. He has laid emphasis upon porosity—upon the absolute need for free diffusion of acid into the material—and this is really, I think, the critical feature in connection with storage cells. What he has said with regard to the need of increasing the porosity of the medium is really the practical key to the position. If we are to improve the discharge and charge rate of cells, it must be by operating in the direction he has pointed out. From a practical point of view his arguments appear to be perfect; but I am not prepared to go with him in the theoretical arguments which he has put forward. If you picture to yourselves what is going on in the cell, you can see at once it is absolutely needful there should be a high degree of porosity conferred upon the material. There is a very large requirement of acid at both plates; and the acid is one which diffuses at a comparatively slow rate. On the one hand, you are, during discharge, depleting the solution of acid, and therefore you are not only varying the resistance and the rate at which chemical change can take place, but you are also perhaps changing its character; while, on the other hand, when you are charging your cell you are loading the pores with strong acid. One can see, therefore, that it is essential that there should be a free passage of acid both into and out of the porous material. In these two respects Mr. Wade has put the case before us in a very clear way. He has given a clear indication of the lines upon which we can proceed in calculating the efficiency of the cell, and he has, I think, led the way so far as practical improvements in the cell are concerned, by insisting very strongly on the need of great porosity.

Professor Ayrton.

Professor W. E. AYRTON: The paper which Mr. Wade has given us on Storage Battery Problems is probably one of the best that it has been our good fortune to listen to for many a long day, and I feel sure that at the present time we should know much more about storage cells, and, perhaps what is more important, we should have much better storage cells, had we been favoured with many papers like Mr. Wade's, combining the same clearness of thought, lucidity of expression, and emphatic direction as to what we ought to aim at doing in order to improve the accumulator. Dr. Armstrong has referred to those very interesting experiments that Mr. Robertson, his assistant at that time, was so good as to carry out for us in 1890 on the analysis of the plugs in the porous, the peroxide plate. Referring to this test, the author, on page 469, says that "In this special instance the previous treatment of the cell was exceptionally favourable, and as on a 12-hour discharge rate its capacity came out about 33 per cent. above its listed value, it had evidently been worked up to a state of efficiency but seldom obtained, still less maintained." Now, why is it absolutely true that the cell was in a state of efficiency seldom attained, still less maintained? Was it because we were dealing with a perfectly new cell or with a cell supplied us by the Electrical Power

[1] Cf. *Royal Society Proceedings*, 1891, 50, 105.

Professor Ayrton.

Storage Company especially for our experiments? Nothing of the kind. The reason was indicated, but we probably did not succeed in impressing upon the world ten years ago what were the conditions necessary for the success of pasted accumulators. The cell which gave those results had been in daily use in my laboratory for quite two years before the experiments were carried out, and these were the words we used in the paper we gave in 1890 on "Notes on the Chemistry of Secondary Cells." (This Journal, 1890, vol. xix., p. 660.) "The cell selected to remove the plugs from had the same size as the cells employed in the investigations described in a previous communication, and was one of the batch of fifty purchased for the Central Institution about the middle of 1888. *Since it first came into our possession it had never been overcharged, never been left discharged, nor permitted to send more than the maximum current allowed by the makers, and*

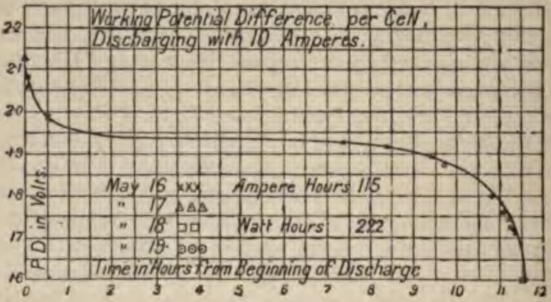


FIG. A.

consequently at the beginning of the present investigation in June of this year [1890] *this cell was in excellent condition.*" And I may emphasise now what we stated at that time—viz., that the proportion of liquid to plates was much larger than is usual in cells. Another condition was scrupulously adhered to, and it is one to which, for a very practical reason, I want to draw special attention. At the commencement of this investigation referred to, ten years ago, we discharged the cells day after day. The experiments were made by successive charging and discharging by automatic machinery, week after week, day and night, without intermission, in order to get the cell into its perfectly normal condition; and the discharge limit was initially fixed, for a reason given in that paper, at 1·6 volts, as shown in Fig. A. We soon found out, however, as explained in the previous paper on the Working Efficiency of Secondary Cells, that we were ruining the cells. For the charging became more and more difficult (it became impossible to put the energy into the cell because the potential difference rose so rapidly), and also that it gradually became impossible to get any considerable amount of energy out of the cell. After a number of experiments in the summer of 1890, we decided that it was because we were letting this potential difference go down too low, and we found if we stopped at 1·8 volt and took off that small fraction of the discharge, instead of ruining

Professor Ayrton.

the cells we were able to make them go through the same cycle with absolute exactness in their repetition. On that occasion the novel fact was pointed out, viz., that the discharge should be stopped when the potential difference fell to 1·8 volts, and we mentioned in that paper that Dr. Louis Duncan and Mr. H. Wiegand, experimenting in the Johns Hopkins University in the same year, had arrived at the same result. I lay so much stress on the fact that if you stop at 1·8 instead of 1·6 volt you keep your cells in good order and do not ruin them, because this last fortnight I have been told by two independent persons —I do not know how far their information is authoritative—that that explains the difficulties of the London Electric Cab Company. A sort of controversy took place in the electrical press last year to this effect: The Electric Power Storage Company had, it was said, entered into an undertaking for 20 per cent. of the prime cost per annum to keep the cells up to a certain percentage of their normal capacity for three years. The Cab Company came to an abrupt end, and one of the electrical papers suggested that probably accumulators were responsible for the difficulty, and rather implied that the Electric Power Storage Company had not fulfilled its obligation. The latter company wrote a letter, which was published in the paper with a very proper apology, to the effect that the Electric Power Storage Company had carried out their obligation absolutely to the letter; and yet still there remained the question that the Cab Company had ceased to exist. I am told, as I say, the explanation was that the Storage Company agreed to keep the accumulators up to a certain percentage of their normal capacity, for 20 per cent. per annum, the cells being used every day and charged every night, provided that they were never allowed to go below the limit that we had arrived at in our 1890 investigation, viz., 1·8 volts per cell. I am told that this was a clause in the contract, but that unfortunately the Cab Company did not in the least appreciate the importance of the condition, and the result was that when the cells began to wear out, when cabs came in and they were tested, the cells were found to have run down to lower than 1·8 volts per cell. The Electric Power Storage Company were able to say, so I am informed, keeping strictly to the agreement, "That cab is outside the contract"; and so one by one they went outside the contract until the whole of the cabs were outside it. The Electric Power Storage Company were quite willing to keep them in order if the condition had been fulfilled. It is quite possible that this is a fact. Another accumulator company, to whom I mentioned this matter, told me they also believed it was a fact, and that they in their maintenance contracts insisted on the cell being stopped at 1·8 and not allowed to fall to an appreciably lower number of volts. If that is so, if the experiments that we have carried out are borne out by all this experience, why do not people realise that adding a mere fraction of discharge energy seen to the right of the ordinate that happens to pass through 11 hours in Fig. A means ruin to the cells and ruin to the company? Why not put prominent volt-meters on the splash-boards of the cab, and tell the cab-driver, "On pain of your life, come home when you see the pointer at 1·8 volts per cell"?

Professor Ayrton.

I will now go to the other most interesting point to which Mr. Wade has drawn attention. He considers that the failure of the cell is mainly due to the want of porosity. There are certain reasons which bear that out, and certain reasons about which I am not sure whether they do or do not bear out his theory, but I should like to put them before him in order that so competent an authority can express his views. The first point is perfectly well known, that in ordinary discharge the potential difference of the cell falls very rapidly at the beginning, though the current is kept quite constant, then very slowly, and then again very rapidly. This first rapid fall, which occurs in the first half-hour or so, does not occur at all in a cell if it has been left charged for a considerable time. Supposing you get one of these cells, as described in the paper, into a perfectly normal condition, charging and discharging without intermission for many days and weeks, the same curve being produced over and over again, for charging and discharging, and then you carefully insulate the cell, take off the wires, and leave it for a fortnight: what is the shape of the curve of the first discharge, when, of course, the strong acid which is put into the pores during the charging has had plenty of time to diffuse throughout the cell? I do not know whether Mr. Wade remembers, but the curve, so far from coming down, starts low and rises a little (see Fig. B). After a period of a fortnight, the cell being well insulated and then discharged, a curve is given which begins to rise as the discharge goes on, and then falls afterwards. The absence of fall at first would tend, no doubt, to bear out the idea that the strong acid put into the pores in charging had had time to diffuse. There was no strong acid in the pores, therefore there was no sudden fall. But what about the rise? How is that explained? You can hardly imagine that the discharge of the cell, which we know produces sulphate, which uses up sulphuric acid, would in any way strengthen the acid, and therefore there does not seem to be any special reason why the potential difference for constant current should begin to rise after a rest.

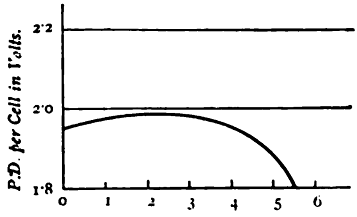


FIG. B.

I now come to something which is even more noteworthy, because it has a very important practical application. There are two ways, of course, in which cells can be charged. They are usually charged with something like constant current, but another method which, I am happy to say, is becoming much used because of its great improvement, is to charge them at constant potential.

Two of my students, Mr. Cahen and Mr. Donaldson, described to the British Association in Bristol the result of an investigation of the charging of a Tudor cell with constant current in the ordinary way and with constant potential. Supposing you take a charge with constant current in the ordinary way: the potential difference must rise. The rise

is very rapid towards the end, and you have a period of much gassing and a considerable waste of energy (see Fig. C). Mr. Wade has given us his explanation of the gassing. Suppose, instead of having a constant current of (say) 20 amperes, with a gradually increasing potential, you start with 2·5 volts constant potential difference (see Fig. D). Initially there is an enormous current (perhaps 180 amperes instead of 20), and as the current rapidly falls, you are able to put in the charge in a fraction of the time; in fact, the major portion of the charge is put in in about 40 or 60 minutes instead of in (say) 3 hours and 20 minutes, and (which is very important) you get no gassing, because the gassing does not occur until the current has been reduced to (say) 20 amperes. Apparently it is not the high voltage that causes gassing; gassing occurs quite at the end of the charge, whether you raise the potential difference to keep the current constant, or keep the potential difference constant and let the current fall. In the former case you cannot prevent gassing without stopping a great deal of the energy being put into the cell; whereas, in the latter case, Professor Ayrton.

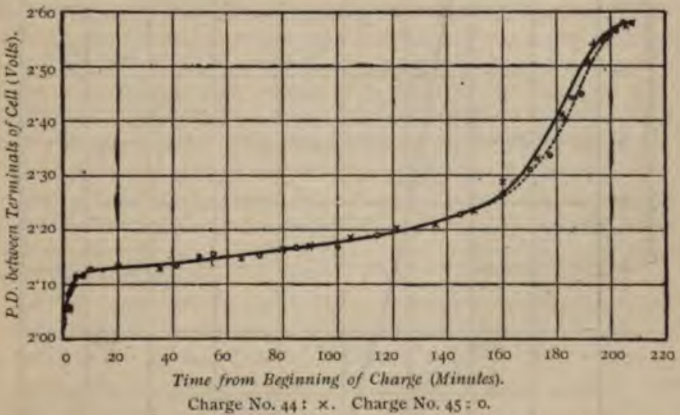
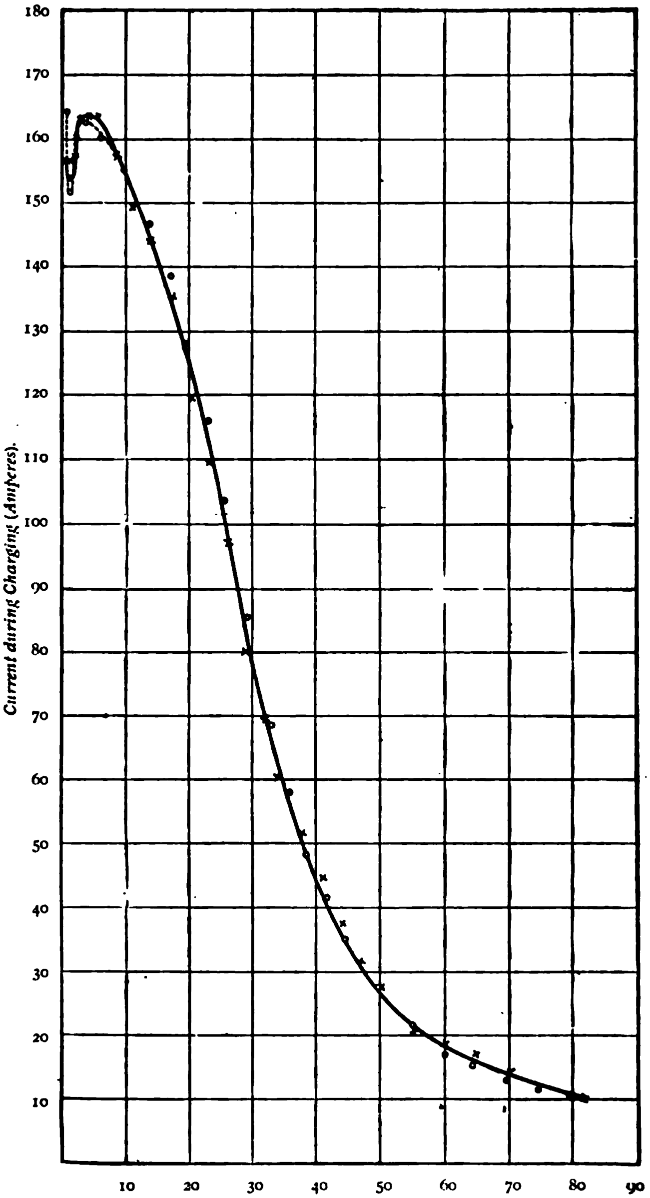


FIG. C.—Tudor Cell Charging at a Constant Current of 20 Amperes.

you can entirely cut off the gassing, because if you stop charging at the moment when gassing commences, you will already have put in almost the whole of the energy required. You might have thought the very large current in charging at constant pressure, owing to its production of very strong acid in the pores, would not, according to Mr. Wade's idea, allow much energy to be put into the cell; on the contrary, this arrangement puts more energy into the cell in a short time than the other puts into it in three or four times the time. Further, not only is more energy put into the Tudor cell at each of the charges at constant P.D. than at each of the charges at constant current, but, what is equally important, more energy is given out by the cell at each of the discharges after a constant P.D. charge than at each of the discharges after a constant current charge. This is shown clearly in the table on page 503:—



Time from Beginning of Charge (Minutes).
Charge No. 44 : ×. Charge No. 45 : o.

Fig. D.—Charging at Constant P.D. of 2·508 Volts.

Professor Ayrton.

Method of Charging.	Watt hours put in.	Watt hours given out.
Constant Current... ...	151·8	123
Constant P.D.	231·2	163

With such an extremely rapid production of sulphuric acid in the pores it might be inferred from Mr. Wade's paper that you could not get much energy in, your cell would act very badly, there would be a great deal of gassing, and the electrolyte would be forced out, etc. For he says in his paper: "The outer layers of active material will absorb more than their due proportion of the current, and by the time they are fully desulphated the inner layers, as yet only partially charged, will be surrounded by abnormally strong acid to enable them to maintain an equivalent voltage. Unless, therefore, the current is prolonged for a time after "gassing" has commenced and the end of the recharge only determined by a sufficiently high potential difference being attained, there is some likelihood of the inner layers not receiving their proper charge at all." But, in practice, you get nothing of the kind. By making the current some 170 amperes at first, and letting it fall as it does fairly rapidly, you first diminish the time of charging by *more* than two-thirds, you prevent all gassing, and put more energy into the cell as well as get more energy out of the cell than you can with constant current. I put that before Mr. Wade because the very important practical result appears somewhat to oppose his theory that the important defect in the existing accumulator is the absence of sufficient molecular porosity.

Mr. Hibbert.

Mr. W. HIBBERT: I confess that, although I have, perhaps, as high an opinion of the paper as that expressed either by Professor Armstrong or by Professor Ayrton, I shall not be able quite so consistently to agree with the author. We began working at this subject in Dr. Gladstone's laboratory in the earliest days of the accumulator, and as I myself worked at every experiment that has been tried there, both on the chemical and on the physical side, I am well acquainted with the history of the subject. Up to the time at which the work was begun, it was the common practice to attribute the actions that were going on to the action of hydrogen and oxygen, and the presence and function of sulphuric acid was altogether ignored. When the first papers were published, the theory advanced was not accepted. Dr. Frankland, in the following year, 1883, advanced the same theory in a slightly different form, and from that day to this there have been investigations by Reynier, Crova, Heim and Kohlrausch, Ayrton, Robertson, etc., all of which tend to confirm the notion, admitted even by Mr. Wade, that the sulphate of lead is the thing which is actually formed in the cells. You will find in the January issue of *Science Abstracts* (Abstract No. 242) an exceedingly good paper by Mugdan which is well worth study, but which I am afraid does not confirm some of the conclusions drawn, and some of the positions taken, by Mr. Wade. To begin with, Mr. Wade

Mr. Hibbert. explicitly says that he founds his position largely upon the fact that the lead on the one side and the peroxide of lead on the other are in allotropic modifications. Dr. Armstrong rightly says that the paper is exceedingly logical, but I fear that its premises are not right. I challenge the position that the lead and the peroxide of lead are in an allotropic condition. The proof of that depends upon experimental trial and examination; and if Mr. Wade wished to put the full benefit of his theory before us, he should have expended his strength mainly upon that particular portion of his work. My reason for challenging it is this: He quotes, in the first place, the work of Darrieus, who described certain experiments tending to show that the lead in the accumulator is in a condition different from that of ordinary lead. Mr. Wade mentions in support of this that any mechanically prepared lead, even in a very finely divided condition, will have but a fraction of the capacity of the lead prepared by electrolysis; and that the lead in a negative plate, if exposed to the air, very rapidly undergoes oxidation, giving rise to a great evolution of heat. I have repeated some twenty times the experiment of Darrieus, which, on the surface, appears to be an easy one, but is not really so; but I have generally failed to get any confirmation of his theory. My reason for doubting the allotropic condition of the peroxide on the other plate of the battery is that Dr. Shields, an exceedingly capable experimenter, determined the electrical resistance of different specimens of lead peroxide, some prepared electrolytically and some by pure chemical agency, and the difference between the specific resistances of the two materials was so small that I think the observation tells very strongly in favour of the idea that they do not differ in any allotropic sense. Moreover, 17 or 18 years ago I made accumulators in which the negative plate was made of lead that had been precipitated from the acetate by means of metallic zinc, a well-known method of getting finely divided lead, and one that does not involve any kind of electrolytic operation. Unfortunately I have not access to Mr. Tribe's note-books, containing the details of these experiments which I am now speaking of, and which were not done in Dr. Gladstone's laboratory; but, as far as I remember, the negative plates containing lead precipitated by zinc showed the same E.M.F. and the same capacity, to all intents and purposes, as the negative plates prepared electrolytically. For these reasons I venture to say that the basis of argument is not sufficiently well founded, and that we have no good reason for supposing that either lead or peroxide of lead are in allotropic conditions. A very great deal depends upon that, and I need not, therefore, follow some of the developments which Mr. Wade founds upon this assumption in the course of his paper.

Dr. Armstrong has intimated that there is a great deal still to be found out. That must be frankly admitted, but it is very important that, in trying to find it out, we should remember what has already been discovered. My reason for mentioning that is the statement on p. 493, that "Fully charged active materials maintain their normal condition with considerable tenacity, but it is quite possible that the very *gradual loss of* capacity so often experienced by negative electrodes, and *for which no* satisfactory explanation has yet been offered, may be due

Mr. Hibbert.

to a change of molecular structure. Clearly there is a tendency here to found explanations in the changes of molecular structure. Yet Professor Ayrton's paper, in 1890, gives the explanation sought. His papers showed that when the cells are allowed to stand, hydrogen gas is, after a time, evolved from the lead plates by simple chemical action. Lead sulphate is being formed in the pores of the lead plate, and necessarily the capacity diminishes with the lapse of time. Professor Ayrton, in a note to that paper, showed that Dr. Gladstone and I had described the same fact a month or two previously in the *Philosophical Magazine*. I have since found that Streintz, a German worker referred to in the paper, had made the same observation before Dr. Gladstone and myself had seen it. But at a still later date I have found that at least two or three years previously Mr. Swinburne had observed the same fact, and described it in the Journal of this Institution. Hence it will not do to go on making new observations until one is acquainted with what has already been done in these matters.

There are three other points I should like to refer to. Mr. Wade has very rightly dwelt upon the importance of porosity. But I venture to draw attention to an addendum to a paper read by Dr. Gladstone and myself "On the Cause of the Changes of Electro-motive Force in Secondary Batteries" in the session following Professor Ayrton's paper (see this Journal, 1892, vol. xxi., p. 440). I quote this at some length because it puts the point very succinctly, and it is worthy of your attention. "Although we did not undertake this investigation with the object of improving secondary batteries, there is one suggestion we should like to make, *i.e.*, the desirability of promoting diffusion as much as possible. We believe that this is becoming more and more the practice among those who make accumulators, and the previous considerations furnish three reasons for such a procedure. It is well known that the accumulation of stronger acid at the lower part of a cell during its working is disadvantageous. This is believed to create differences of current-density in different parts of the plate, and we have shown that it will also give rise to potential differences of fairly large value on each of the plates, and thus produce local action and the formation of lead sulphate. This inequality would be diminished if the diffusion of the acid could be promoted." Mr. Wade will forgive me, I am sure, when I say that that appears to me to be almost a paraphrase of a passage in Mr. Wade's paper. This is the second reason: "The fall of E.M.F. at the close of discharge leaves a large fraction of the effective material not acted upon. This is mainly due to the weakness of the acid against the plates on account of the interstices being so much clogged, and it would be counteracted to a considerable extent if the diffusion could be increased. When a cell has been discharged at below 1·8 volts, there occurs the destructive action called 'scaling.' We are disposed to attribute this to abnormal chemical action arising from the very weak acid; and if this be true, increased diffusion would in this case also act as a remedy."

Again, I should like to refer to the attempt already mentioned by Professor Ayrton to give an explanation of why it is advantageous to cut off the last part of the curve of discharge. If I might commend any

Mr. Hibbert. papers, it would be those contributed by Professor Ayrton and three of his students to this Institution in the year 1890. The paper which I have already referred to, contributed to the Journal by Dr. Gladstone and myself subsequent to the publication of those curves, in my opinion reveals the reason. The main argument is, that as the acid strength in the working materials changes, the electro-motive force and therefore the potential difference vary very largely. In the paper we give repeated experiments to show that when the *electro-motive force* has a value of 1·76, the strength of the acid of the pores of the plates is 1·2 per cent. Again, that when the electro-motive force has fallen to 1·5, the amount of the acid in the pores is a trace only—not a measurable quantity. There is acid present; it is not pure water, but it is only just removed from it. Now, Professor Ayrton's curve is not an electro-motive force curve; it is the potential-difference curve; that is to say, the electro-motive force is a trifle higher in the discharge curve than in the potential-difference curve. But if you will compare the data given in our paper with the data derived from Professor Ayrton's curve, you will see—and it is stated here (Journal, 1892, p. 427)—that it is almost absolutely certain that at that time the acid had altogether gone from the pores of the cell, and inside the pores, where the chemical actions are at play, you have, to all intents and purposes, pure water. So long ago as the year 1882 Dr. Gladstone and Mr. Tribe published not only what is called "the double sulphation theory," but in the same series of papers, including their little book, they also showed that if at any time or for any reason the acid chances to disappear, the chemical action changes altogether; that is to say, you no longer get these normal sulphates. In the presence of liquid which no longer contains the requisite SO_4, there is formed a hydrated oxide. Therefore, after the potential difference reaches 1·8 volts in the discharge curve, you are dealing with a region in which the chemical action can no longer be in accordance with the double sulphation theory. There are now molecules of hydrate of lead, soluble, and therefore travelling in the water. These subsequently form sulphate, not in the electrolytic circuit, where commonly sulphate is formed, but in the regions where it is no longer so susceptible to the action. Formed in this way, it gives rise to expansive forces that tend to produce the thick scales and sediment at the bottom of the cell. That is the reason why Professor Ayrton and his colleagues got the sediment which Mr. Robertson analysed and found to have a composition of $PbO_2 + PbSO_4$, formed under conditions when the cells were being discharged down to this particularly low point.

Finally, it is stated in the paper that the sulphation theory cannot be altogether true, because there ought to be a definite equation for a definite E.M.F. The E.M.F., or rather the potential difference, is continuously falling, and as a consequence you get the argument that the equation cannot hold strictly true all through. That is a perfectly valid position to take, but it ignores the fact that in writing the equation in the tolerably simple form, H_2SO_4, is sulphuric acid at large. But no one has the right to ignore the fact that water is there, although it is commonly ignored. If the equation is to be put in a different form, what

ought to be done is to write $H_2SO_4 . n\ H_2O$, and since n is constantly varying, the E.M.F. ought to—and does—change very gradually. There is now a definite equation for a definite E.M.F. Mr. Hibbert.

Mr. Wade explains the well-known phenomena which occur at the end of discharge by supposing that there is then a sudden rise in the resistance of the active masses. When these reach a particular degree of sulphation, the resistance passes through a critical value, thenceforward increasing much more rapidly.

Now, the degree of sulphation of a cell at the end of discharge is practically identical with that at the beginning of charge, and if Mr. Wade's hypothesis be well founded, there ought to be great similarity in the final resistance in discharge and the initial resistance in charge. But this is not the case. On the contrary, in the change from the finish of discharge to the beginning of charge, the resistance falls to seven-elevenths of its value. (*J. Inst. Elec. Engrs.*, 1890, pp. 591, 592). Clearly the higher resistance of the one cannot be due to the fact in which both agree, namely, the degree of sulphation. Moreover, it is when there is least sulphate on either plate, that is, at the end of charge, that the resistance has its highest value.

Mr. G. L. ADDENBROOKE: I should like to point out that, if we can, as Mr. Wade holds out some hope of doing, increase the capacity of accumulators for the same price by about 20 or 30 per cent., it would increase the opening for accumulators not by 20 or 30 per cent., but probably by three or four times. There are a great number of places where accumulators could be used with great advantage if we could thus increase their output for a given expenditure, and if they could be maintained for something like the amount at present necessary. Mr. Addenbrooke.

Mr. G. C. ALLINGHAM: I would like to point out that the primary action in the discharge of a cell is really one of single sulphation. The sulphuric acid is electrolysed during the discharge; we get hydrogen ions given off at the peroxide plate, and sulphion ions given off at the spongy-lead plate. The sulphion ions, combining with the spongy lead, form a sulphate exactly in the way Mr. Wade has described; but the hydrogen ions first of all simply reduce the peroxide to a lower oxide. The ultimate oxide produced is probably the sesqui-oxide—Pb_2O_3. This formula, which corresponds to what Mr. Wade calls 50 per cent. sulphation, seems to me to explain very simply how it is that the active material can never be discharged below this point. The lead in the peroxide has a valency of 4. When the peroxide plate is fully discharged, the valency of the lead becomes 3. The sesqui-oxide which is produced by the reduction of the peroxide by the hydrogen ions is then acted upon by the sulphuric acid and produces a sulphate. As a matter of fact, it is probably not Pb_2O_3, but a hydrate, such as $Pb_2(OH)_6$, that is formed, and the action of the sulphuric acid on this produces a basic sulphate, $Pb_2(OH)_4SO_4$, the formula of which corresponds with Mr. Wade's $Pb_2O_2SO_4$, except that the oxygen is replaced by hydroxyl, which I think is rather more probable. This way of looking at the matter seems to me slightly to modify one or two of Mr. Wade's arguments. Thus, the sulphation of the peroxide plate being produced by chemical action, depletes the pores of acid, exactly Mr. Allingham.

Mr. Allingham.

as Mr. Wade has described. But the acid which is used for the sulphation of the spongy-lead plate is carried to it electrolytically. The sulphion ions travel from the body of the liquid: therefore, as far as I can see, the sulphation of the spongy-lead plate is not carried out at the expense of the acid in its immediate neighbourhood and in its pores at all. Hence there seems to be no reason why the acid in the pores of the spongy-lead plate should be weakened at all. If it were possible that the spongy-lead plate could be imperfectly sulphated, the acid in its pores would positively get stronger, owing to the sulphion ions carried to the plate not being entirely absorbed by the plate. Any clogging of the spongy lead plate would therefore be due, not to the exhaustion of the acid in its pores, but merely to the conductivity of the active material being higher than that of the solution, causing the outer layer to take more than its fair share of the load.

During the charge, of course, acid is liberated at both plates, but according to this view, more acid will be liberated at the peroxide plate than at the spongy-lead plate.

Mr. Wade's paper, to my mind, shows the importance of diffusion, not only into the pores of the plates, but also in the body of the cell. If there were no diffusion in the cell, we should gradually get all the acid exhausted from the body of the cell and collected at the two plates; and this seems to me to render hopeless the various attempts that some inventors have made to make so-called dry accumulators by filling up the spaces between the plates with absorbent materials.

It is probable that the compound Pb_2SO_4 is formed by the sulphation of the spongy-lead plate during discharge, as Mr. Wade suggests; but if so, I think it should be looked upon, not as a compound of metallic lead with normal sulphate, but as the subsulphate, or sulphate of monad lead. There does not seem at present to be much experimental confirmation of the existence of such a compound. According to this view, the normal discharge produces a sulphate of triad lead on the peroxide plate, and a sulphate of monad lead on the spongy-lead plate, and what is commonly called "sulphating" is the formation of the sulphate of diad lead ($PbSO_4$) which occurs if the sesquisulphate on the "peroxide plate," or the subsulphate on the "spongy-lead plate" be further discharged. I venture to think that this explanation sufficiently accounts for the phenomena, without the necessity for assuming that the active material has a complicated polymeric molecular structure.

I think "sulphating" may always be accounted for by overdischarge of the active material, either general or local. Thus rapid discharges may overdischarge the surface of the active material, producing a skin of white sulphate. If the lead grid or support of the peroxide plate is accessible to the acid, there will be a P.D. set up between it and the peroxide active material, producing local currents which may eventually overdischarge the portions close to the support, causing the sulphating at the grid which is so often noticed. The spongy-lead plate may also be overdischarged by local action. This local action is exactly similar to that on the zinc in a primary battery and is caused by the P.D. set between the lead and more electronegative metals, which exist as ities in the spongy lead itself, or in the solution, from which they

are deposited on to the spongy lead during the charge. These particles of metal produce local currents, which ultimately produce patches of sulphate, with evolution of hydrogen, especially if the cell be allowed to stand for a considerable time on open circuit. These impurities, and the sulphate they produce, gradually clog the spongy-lead plates, and cause their capacity to diminish in time; the effect of reversing them is to redissolve the impurities in the acid, and purify the spongy-lead active material. This reversal should always be carried out with dummy peroxide plates, and the acid used during the operation should not be used again in the cells, as it of course contains the impurities out of the spongy-lead plates. The great lesson taught by the decrease in capacity of spongy-lead plates, which troubles storage battery makers so much, is to keep all the materials and acid used for the battery as pure as possible, and neglect of this precaution was, I believe, one of the chief causes of the early troubles experienced with storage batteries. Mr. Allingham.

The gradual fall of electromotive force during discharge may be due to the variation of the adjuvant E.M.F. produced by the chemical action of the sulphuric acid on the Pb_2O_3 at the peroxide plate, which falls as the strength of the acid round the peroxide plate falls.

Mr. W. R. Cooper: Although I appreciate the clearness of Mr. Wade's paper, yet I cannot help feeling that it is a mistake to introduce further complications into this subject, which is already very complicated, if it can possibly be avoided. One feels tempted to ask, Are all these complications really necessary? They have been brought about by various causes, among which may be mentioned the attempts to deduce a satisfactory value for the E.M.F. from the Kelvin equation. The more general equation due to Helmholtz is generally disregarded for unaccountable reasons. Further, most thermo-chemical data are inexact, and have been determined under conditions which differ from those in the cell. If the cell is looked upon as a primary one consisting of lead, sulphuric acid, and lead peroxide, the voltaic reaction which suggests itself is simply the formation of lead sulphate at the lead plate, the lead peroxide acting as a depolariser and being reduced by the polarising hydrogen to PbO, or metallic lead, any sulphate formed at the peroxide plate being due to a secondary reaction. This view does not meet with approval because the E.M.F. deduced from these reactions by thermo-chemical data is much lower than the observed E.M.F. of a secondary cell. But it is necessary to remember that the secondary cell differs very considerably from the primary cell. The electrolyte is not merely sulphuric acid, and that which is in the pores may be relatively concentrated. Spongy lead may also differ considerably from ordinary lead. Consequently, the usual thermo-chemical data may be inapplicable. This point of view has been taken up by M. Darrieus, who finds that the voltaic difference between spongy and ordinary lead is 0·34 volt; and he concludes that the calculated E.M.F. is equal to that observed if such considerations are taken into account. Although Mr. Hibbert has apparently failed to confirm the results of M. Darrieus, I do not think that this simple view has received sufficient attention. A simple view is preferable to a complicated one, and it is to be hoped that further investigations will be carried in the direction indicated by M. Darrieus. Mr. Cooper.

fr. Cooper.

Turning now to the paper itself, Mr. Wade suggests a complex molecule for lead and the various lead compounds. I think that there must be some misunderstanding on this point, as this view is held generally for all solids. In the case of spongy lead, it would be expected that the molecules are *less* complex rather than *more* complex than those of ordinary lead, as this would more easily account for greater activity. We should expect activity to increase as the number of atoms in the molecule diminishes, for it is only necessary to go to the limit of atomic sub-division to obtain the maximum of activity.

The author also suggests various complicated sulphates which conduct, but which are liable to pass into ordinary lead sulphate, and thus lose their conductivity. There does not, however, appear to be any reason why these complicated salts should be better conductors than $PbSO_4$, and it is questionable whether the change in the conductivity of lead sulphate which is observed when "sulphating" takes place cannot be more reasonably explained by simpler changes such as crystallisation, hydration, etc.

The various complicated salts proposed by the author are theoretically somewhat improbable, and it is doubtful whether they give a really simpler explanation than that afforded by mixtures.

Mr. Swin ourne.

Mr. J. SWINBURNE: Mr. Wade goes over a great deal of ground that has been traversed ten or even twenty years ago, without really giving any new reasons for his rather revolutionary ideas. Most of the phenomena, I think, of secondary batteries can be explained on the simple sulphate theory that has been held now by a great many people for very nearly twenty years. There are, of course, matters which obscure the result. The first is that the sulphate of lead apparently is a non-conductor. Mr. Wade seems to regard the materials as mixtures, or rather compounds of very curious chemical composition; but most of these effects, I think, can be explained by remembering that the sulphate formed is an insulator, and that the sulphuric acid in the coating is apt to get used up during discharge, and therefore the E.M.F. is dependent on the strength of the acid in the pores which gets used up. In dealing with the question we ought always to remember that the chief chemical action in such a case as running a secondary battery down, is the formation of water. Water is so cheap that we are apt to look upon it as unimportant; whereas in modern chemistry we ought to regard, generally, the formation of water as the vital part of the equation. I see Mr. Wade says that sulphate of lead cannot be reduced or oxidised. That theory or experiment was first mentioned by Lord Kelvin something like twenty years ago, but, unfortunately, it is not the fact. It is simply that the sulphate of lead is an insulator. It insulates very thoroughly, but if you get sufficient pressure you can take pure sulphate of lead and either reduce it or oxidise it. Ordinarily it is a question of getting contact, and if you mix a very little litharge or red lead, or something of that kind, you will find your sulphate of lead, although it may have been precipitated, will be perfectly amenable, and will do what you want it to do. I proved that in 1882, and it is rather 'mportant matter. On the other hand, Mr. Wade seems to think tery cannot possibly run down to pure sulphate, that it may

run down to one of his curious compounds, and the compound afterwards, for some reason of its own, may change to pure sulphate. As a matter of fact, if you take a thin coating you can very often run it down till it is quite white, and the white coating of the reduced plate is often such a thorough insulator that a piece of lead in apparent contact—even, perhaps, forcibly pressed against it—will not make contact. Any one who has not had very much to do with batteries will be astonished to find the difficulty of securing contact in the reduced plates, and it is always due to these very thin films of sulphate. The coating, under these circumstances, with that explanation, will naturally tend to go down into sulphate, or go up into sulphate, as the case may be, until the sulphate practically insulates it. The mixture of a conductor and an insulator will generally conduct till you get down to about 15 per cent. of the conductor among the insulator, and then you generally find that it comes to a point at which it will no longer conduct. I am thinking now, for the moment, of a large amount of work that has been done lately in making Nernst and other lamps. The phenomena of mixtures of conductors and insulators is very curious. But I think they probably account for the whole of the apparently anomalous actions of the cells. The fact that a cell will sulphate, that is to say, will go from a conducting into a non-conducting body, is probably explained by the conducting body consisting of sulphate of lead, containing either very little peroxide mixed up with it, which will conduct, or very little reduced lead. Reduced lead, especially if left in contact with acid, is very apt to go up into sulphate of lead and give off hydrogen. If you have not a very strong pressure you cannot get it into contact with your support, and cannot reduce it again. I only want to urge that, except for the small phenomena which are generally explained by such things as the difference of strength of acid in the coating, and the difference of conductivity due to the insertion of sulphate of lead, which has a very large bulk in comparison with what it is formed from, I think these things explain most of the phenomena. I would also urge that in all scientific inquiries, when you have a very simple explanation and a very complicated one, there are a large number of minds which habitually prefer the very complicated one. I must say I am one of those who prefer the very simple explanation. Mr. Swinburne.

[*Communicated.*] Since the meeting I find that many people cannot understand the formation of sulphate of lead on the peroxide plate on discharge, because they say the H_2SO_4 is split into H_2 and O, of which the H_2 takes one O of the PbO_2, leaving PbO. The PbO may then be acted upon by more H_2SO_4, making $PbSO_4$; but the last is a secondary reaction which has nothing to do with the electro-motive force of the cell. There is no reason to consider this a secondary reaction. In dealing with electrolysis we must take care to avoid confusing hypotheses, made for the purpose of explaining phenomena to students, with the phenomena. This splitting up of the change of PbO_2 into $PbSO_4$ in two steps is purely academical; it has nothing to do with facts.

The question as to whether the formation of sulphate is primary

Mr. Swinburne.

or secondary can be determined by the reversibility of the cell. If the energy of $H_2SO_4 + PbO = PbSO_4 + H_2O$ is wasted as local heat, it can only appear in the electro-motive force of charging; not of discharge. The question of the alleged extra electro-motive force of spongy lead can be tested by reversibility, and also by direct comparison. In direct comparison the lead must be clean, and the surface should be specially exposed when in place. The least trace of oxidation, *i.e.*, sulphation, will falsify the reading. Amalgamation will give an effective clean surface.

Mr. FitzGerald.

Mr. D. G. FitzGerald [*communicated*]: I have read with great interest the advance-proof of Mr. Wade's paper, kindly forwarded to me. Whether or not it may have any influence upon the manufacture or working of accumulators in the future, it is certainly a valuable contribution to the theory upon which such manufacture and working should be based, and it throws light upon subjects of which the presumed explanations have with some reason been regarded as incomplete, puzzling, or unsatisfactory, when not absolutely fallacious. I am pleased to find that I am in general agreement with Mr. Wade on most points—the more so from having apprehended that the contrary might be the case.

Thus, in regard to the original battery-equation given by Messrs. Gladstone and Tribe, and embodying the "double sulphation" theory, I am quite in accord with Mr. Wade as to its substantial accuracy when taken in the limited sense in which it was put forward, viz., as signifying that, in the discharge of the cell, sulphuric acid reacts upon lead protoxide at both electrodes, producing equivalents of lead sulphate. The equation indicates nothing as to the extent to which the reaction may be carried; it is similarly indefinite as to the form or condition taken by the sulphate in either electrode. In my paper "On Reversible Lead Batteries," read before the precursor of this Institution on May 10, 1887, the only modification I could find to make in this equation was one indicating that the sulphate of lead formed in the peroxide element is not necessarily the full equivalent of that formed in the spongy-lead plate. This is the case when free access of sulphuric acid to the peroxide does not obtain, by reason of the insufficient strength of the electrolyte, or in consequence of the 25·52 c. in. of hydrogen, per ampere-hour, oxidised into water at the peroxide plate. I therefore preferred to write the equation as follows:—

$$PbO_2 + 2\,H_2SO_4 + Pb = \underbrace{PbO + H_2SO_4} + PbSO_4 + H_2O.^*$$

It was duly admitted, however, "that the compounds bracketed together (when in intimate contact) react upon each other; so that the *final* result may be expressed by:—

$$PbO_2 + 2\,H_2SO_4 + Pb = 2\,PbSO_4 + 2\,H_2O;"$$

which is the equation of Gladstone and Tribe.

* *Journal of the Society of Telegraphic Engineers and Electricians*, vol. xvi., p. 175.

Mr. FitzGerald.

But a too literal reading of this equation, from the point of view of practice, has been the cause of much of the misapprehension and confusion that have occurred in relation to the theoretical explanations bearing upon the lead secondary cell. It has been so crudely interpreted that, if any one ventured to assert that—in the absence of what is too well known as *sulphalation* or *sulphation* in the worse signification of the terms—there is never any free, normal or uncombined sulphate of lead in the partly discharged peroxide element, he was referred to the above equation as a sufficient refutation of the heresy. If he pointed out that peroxide of lead, when reduced, either by heat, or by hydrogen, alone or in conjunction with an acid, always tends to form exothermic compounds of the products of deoxidation with residual peroxide, the equation was quoted as a contradiction. If he insisted that the complete conversion into lead sulphate of given equivalents of spongy lead and peroxide is an impossibility, and that such conversion practically occurs only to the extent of about 50 per cent., he was told that he was denying data put forward and accepted by high authority. And if he ventured to affirm that the calorific results obtained in the complete conversion into lead sulphate of ampere-hour or gramme equivalents of spongy lead and lead peroxide are wholly insufficient to account for the production of an E.M.F. of 2 volts., corresponding to this conversion in the same manner as the E.M.F. of a Daniell cell corresponds to the heat effect of the reaction between zinc and sulphate of copper, he was told that the calorific values must be inaccurate ; for there was the equation, and there undoubtedly was the E.M.F. of 2 volts.

At the time (1883) when Messrs. Gladstone and Tribe published their excellent little monograph on "The Chemistry of the Secondary Batteries of Planté and Faure," what may be termed a theoretical or abstract battery-equation was needed and was duly supplied. What may be called a practical or concrete equation of discharge, approximatively embodying quantitative details, was scarcely then possible ; for this a more extended experience, and work such as that of Professor Ayrton and his assistants, in conjunction with Mr. G. H. Robertson, were needed. In the second part of his paper (p. 485), Mr. Wade gives what is virtually such an equation, although the excess of sulphuric acid needed to give conductivity to the electrolyte towards the end of the effective discharge is not therein considered. In equation form, Mr. Wade's values are as follow :—

$$2\,Pb + SO_4 + H_2 + 2\,PbO_2 + H_2SO_4$$
$$= PbSO_4 + Pb + PbO_2PbSO_4 + 2\,H_2O.$$

This agrees with an equation—in which are embodied additional *data* in relation to the electrolyte—which will be found in my little work on Lead Accumulators, now slowly making its way through the press. In this equation the atomic weights represent the dyad gramme-equivalents, corresponding to 53·6 ampere-hours ; and these weights *halved* correspond to the monad gramme unit of electrical quantity (26·833 ampere-hours). It is as follows :—

Mr. FitzGerald.

$$2\ Pb + 4{\cdot}25\ H_2SO_4 + 69{\cdot}4\ H_2O + 2\ PbO_2$$

$$= Pb + PbSO_4 + 2{\cdot}25\ H_2SO_4 + 71{\cdot}3\ H_2O + PbO_2PbSO_4.*$$

In this particular case, the initial specific gravity of the electrolyte will be 1·182, and the final specific gravity 1·106.

The peroxide of lead which is active, and which alone is considered in quantitative equations, does not include any that may be contained in the compound PbO_2PbSO_4 (in which $PbSO_4$ replaces the PbO in lead sesquioxide) which may remain unaffected by the process of charging. It is interesting to observe that, according to the figures given by Mr. Wade, the proportion of this residual compound must often in practice be very considerable. The same may be the case with the residual sulphate remaining, after charging, in the spongy-lead element. The complete reduction to sulphate of 1 lb. of lead peroxide, if it could be effected electrically, would correspond to 102·5 ampere-hours (half of which quantity would be debited under an E.M.F. falling rapidly from 1·8 to less than 1 volt, and more slowly to zero). But, since the almost inert compound PbO_2PbSO_4 is formed when half the peroxide is reduced, the maximum output per lb. of peroxide will be just half the above value, viz., 51·25 ampere-hours. But if, as stated on p. 469, "in practice, pasted electrodes hardly ever give more than 30 to 40 ampere-hours per pound of positive or negative active material; while about half these values is probably a more usual figure"—and this statement I fear, cannot be contradicted—the proportion of active material actually electrolysed must be less than 30 or 40 per cent of the whole. The practical possibility of improvement certainly appears to be here indicated.

Many other points of interest in Mr. Wade's paper might be referred to, and will doubtless receive consideration in the discussion.

Mr. Du Pasquier.

Mr. A. E. DU PASQUIER [*communicated*]: Mr. Wade's excellent paper will, I am sure, be much appreciated by all the members of the Institution. The use of secondary batteries is so extended, that few of us have not at some time or other had to do with them, and perhaps been morally responsible for their well doing. Lead entering so largely into their composition, I am afraid this has very often been a heavy burden; in fact I have met many engineers who regard a battery as an unavoidable evil. Not, I think, that complaints of the behaviour of secondary batteries are so frequently heard nowadays, but because so little is known about them, and that little is so nearly confined to those interested in their manufacture, that if anything goes wrong with a cell the engineer feels that he is quite helpless to assign a cause for its failure, or to remedy it if found: a feeling to which no self-respecting engineer likes to confess. After reading Mr. Wade's ingenious explanation of the complicated reactions that take place in the charge and discharge of a cell, engineers will perhaps regard their batteries with increased interest. I had long thought of requesting to be allowed to read a paper on a similar subject, before [illegible] as Mr. Wade has so admirably forestalled me, I

[illegible] *ctrical* Engineer, January 21, 1898, p. 74.

Mr. Du Pasquier.

am glad to have the opportunity, not of criticising his remarks, but of throwing, perhaps, a little more light on some of the points he has raised.

Mr. Wade, early in his paper, speaks of the undoubted difference that exists between the finely divided lead electrolytically prepared on the negative plate of a battery, and finely divided lead mechanically prepared. An experiment I carried out some eight years ago bears upon this interesting point. A mechanically prepared porous lead plate was heavily sulphated by being made the anode in a solution practically consisting of a mixture in certain proportions of sulphuric acid and nitric acid, the current density being kept very low to prevent the formation of any peroxide. It was then placed in a cell containing a zinc plate in a solution of common salt, and left on short circuit for some time; by this means the lead sulphate was perfectly reduced to finely divided or spongy lead, and the plate looked to all intents and purposes a fully charged negative. It was then mounted against freshly charged peroxide plates in dilute sulphuric acid of the usual specific gravity, but no discharge could be obtained from it; on receiving a charge in the ordinary way it gave a very fair capacity, and yet one may almost call the action in both cases electrolytic—certainly the hydrogen liberated is in an equally nascent state. If this sulphated plate had been made the negative in a sulphuric acid solution directly the sulphate was thoroughly reduced, it would have given its full capacity. And so, too, with the peroxide plate; if a plate is pasted with chemically prepared PbO_2 no capacity can be obtained from it until it has received a charge; a fact which bears out Mr. Wade's belief that the lead peroxide and the finely divided lead in a fully charged cell cannot be the normal PbO_2 and Pb, but an allotropic modification thereof.

Mr. Wade, in speaking of the increase in the internal resistance of a cell on discharge, says that "it is most rapid when the molecules of the active materials have attained the respective proportional compositions of $Pb_2O_2SO_4$ and Pb_2SO_4." This point will probably be at about 1·8 volts, or when the cell has just finished its useful discharge, and on analysis, he goes on to say, "there will be found about 40 per cent. of unaltered peroxide of lead on the positive, and uncombined lead on the negative." These figures of Mr. Wade's are probably based upon pasted types of plates, or I, without knowing it, am the fortunate possessor of the secret for obtaining "95 per cent. porosity peroxide." The following figures, rather at variance with those given by Mr. Wade, are taken from an experiment of mine on a new type of plate with a very extended surface. Two of these small plates, identical in every way, were taken, electrolytically formed, and charged up fully; one was then discharged against strong negatives, and gave a capacity of 25 ampere-hours to 1·7 volts, which is the capacity we invariably get with this type of plate, so treated.

The two plates were then broken up for analysis, and such is their nature, that though they are perfectly homogeneous, the lead forming the active surface of the plate can, with a little trouble, be detached (for purposes of analysis) from the lead that forms essentially the frame,

Mr. Du Pasquier. and which in no way contributes to the capacity of the plate—in fact, if anything, detracts from it.

PARTICULARS OF ANALYSIS.

	Charged Plate.	Discharged Plate.
Weight of Pb unattacked in grammes ...	127·736	112·787
Weight of $PbSO_4$	·615	144·158
Weight of PbO_2	134·05	22·440
	262·401	279·385

It will be seen that the charged plate had evidently rather more lead available for conversion into active material than the discharged one, and would probably have given a higher capacity. Dealing with the discharged plate, 144 grammes of $PbSO_4$ would correspond to about 113 grammes of PbO_2, making a total of 135·5 grammes of PbO_2 for discharge purposes, of which about 84 per cent. was utilised instead of the 50 per cent. quoted by Mr. Wade. Adopting Mr. Wade's figures of 102·5 ampere-hours per pound of PbO_2 (= ·226 ampere-hours per gramme of PbO_2) converted into sulphate, 81·7 per cent. of the theoretically possible capacity for the 135·5 grammes of PbO_2 present, was obtained. This very favourable result is obtained on the lines Mr. Wade so ably indicates, viz.: 1st—A very extended surface, so arranged that the acid has free passage right through the plate, and that, as the acid in the pores of the plate weakens on discharge, there is nothing to prevent it rising up, by simple gravitation effect, to the top of the cell, making room for the stronger acid in the body of the cell to take its place; although I have never been able satisfactorily to prove this, I am satisfied that this action of discharge actually gives rise to currents in the electrolyte tending, if unimpeded, to keep the electrolyte at a uniform strength. And 2nd—A very low specific gravity peroxide (I have never been able to get satisfactory specific gravities for peroxide, portions from the same sample varying between 5·25 and 6·8), probably about 45 per cent. porosity. I may say that, at present, there are mechanical difficulties in increasing the size of these plates, but these we hope shortly to overcome. Although these figures show that Mr. Wade is incorrect when he says that "a cell is incapable of further discharge when the active material on the plates has the composition $Pb_3O_2SO_4$ and Pb_2SO_4," I agree with him very largely in the main, and believe that the true explanation of these reactions must be sought on the lines he indicates.

Returning again to the allotropic differences between substances represented by the formula PbO_2, another instance occurs to me, which may be of interest. In a certain formation process used very largely by me at one time, the process was divided into two parts, or baths; in the first bath a certain number of ampere-hours charge per square centimetre of surface was given, at the end of which the positive plates—which were of the herring-bone type—were covered with a dark-brown, almost lustrous, very thin film, or skin, of what was *apparently* PbO_2 so thin that it was impossible to estimate its thickness

Mr. Du Pasquier.

as it could not be detached from the plate. At this stage the plate had no appreciable capacity. The plates were then put into an ordinary dilute sulphuric acid bath specific gravity 1·180, and on charging a marvellous change took place; this film or skin gradually expanded until, at a certain stage, the grooves between the ridges or teeth of the plate were completely blocked up with a very crystalline, light-coloured peroxide, evidently of a very porous nature, but perfectly hard and adherent, the plate being then possessed of a very high capacity, whereas a new plate given a short charge in sulphuric, and receiving a similar coating of PbO_2 in point of thickness, might be charged for ever in this density acid without expanding or its capacity much increasing.

Passing on to what Mr. Wade rightly calls the most interesting of all the phenomena observed in storage cells, viz., Reversal. A short time ago I should have said unhesitatingly with Mr. Wade, that if the positives were the weaker element in a cell, its E.M.F. curve was more sustained, whereas if it was the negative that were weak the fall off was much more rapid; but in a number of very careful experiments carried out lately I have been quite unable to satisfy myself that this is so, and am strongly of the opinion that it depends upon the differences in the capacities of the two plates; if either plate has a much larger capacity than the other the fall off is more rapid, as though, to give a rough illustration, the stronger plate upholds the weaker till its last gasp, when it suddenly collapses, whereas if both plates have approximately the same capacity the E.M.F. of the cell will tail off more gradually. With regard to the possibility of reversal actively taking place before all the PbO_2 or Pb has become converted into $PbSO_4$, I think there can be no doubt that this is not only possible, but that it is what actually happens. If a cell is discharged down to zero, and the current rate is still maintained from some external source, and the E.M.F. of the weaker plate (say the negative) observed by means of a charged negative proof plate, in a very short time the volts will rise from zero, or almost zero, to 1·5 to 2 volts; and assuming, as is certainly true for pasted plates, that not more than 60 per cent. has been converted into $PbSO_4$ in discharge down to the zero point, the ampere-hours given to the plate in this time would not have been sufficient to convert all the 40 per cent. remaining Pb into $PbSO_4$, but the high E.M.F. observed is proof of the presence of PbO_2 notwithstanding. If in any cell the two sets of plate happen to have exactly the same capacity, the reversal takes place immediately the E.M.F. falls to zero. Perhaps it is as well to distinguish between the real zero, *i.e.* the point at which the two equal-capacity plates are absolutely exhausted, and there no longer exists a potential difference between them, and the apparent zero—that is, the point in discharge when a voltmeter placed across the bars of the cells gives no deflection. The internal resistance of a cell gives rise to a counter E.M.F. reaching at this extreme end of discharge as high a figure as 0·45 of a volt, so that the apparent zero is reached when the E.M.F. of the plates have fallen to 0·45 volt; as it continues to fall below this point so the difference appears as a reversed E.M.F. on the voltmeter, till when the real zero is reached it has the value of about

Mr. Du Pasquier.

—0·45. I have actually been observing the volts of a cell on a potentiometer when this has been happening, have seen the volts drop to zero, and the beam from the galvanometer glide past the zero quicker and quicker till it has gone off the scale and the leads had to be reversed to follow it. When it attains the value of about —0·45 volt for ordinary current densities there is a slight pause, and again a noticeable pause at about 1·5 volts, after which it climbs steadily up and gives the usual E.M.F. curve of a charging cell.

It is very seldom that the capacities of the plates are so equal; as a rule one will reverse considerably before the other: in this case, roughly speaking, the time elapsing between, when the zero is reached, and an E.M.F. of more than one volt in the opposite direction is observed, is a measure of the capacity of the stronger plate.

There is another very interesting phenomenon connecting with the reversal of negative plates of the Planté type, that is to say plates of large surface and thin layers of active material, which I have often observed, and that is that at the point of complete exhaustion there is a violent ebullition of gas, collecting in large bubbles at the top of the plate. This gas is hydrogen; it does not seem possible to account for it electrolytically, and perhaps the explanation may be that at this stage these unstable allotropic modifications of $PbSO_4$ break up spontaneously into the real and more stable $PbSO_4$ with evolution of hydrogen. I have never observed it with any form of pasted negative where the diffusion is imperfect.

Mr. Robertson.

Mr. G. H. ROBERTSON [*communicated*]: As the adjournment of the discussion of Mr. Wade's most interesting and suggestive paper has enabled me to have it read over to me, I now gladly avail myself of the opportunity afforded me by the courtesy of the Council to make a few remarks on it, and the more especially so since the analyses made by me some years ago have been frequently referred to, both in the paper and in the subsequent discussion.

Mr. Wade has stated his theory of the chemical action occurring in lead batteries clearly, and backed it up with well-reasoned arguments, but I do not think that my analyses and report lend quite as much support to his theory as he appears to think that they do. The fact is, none of the products examined by me could be in any sense considered homogeneous, with the exception of the positive and negative plugs at the end of charge. At all other times the positive plugs consisted of mixtures of more or less unreduced peroxide of lead, lead sulphate and a brown material varying in colour from a dark sepia to a very light shade of the same hue. On treating this brown substance with acetate of ammonium in the cold, no evidence could be found that it consisted of anything except the sulphate and peroxide of lead, and therefore, as described in my report, in the quantitative analysis I only determined the percentage of peroxide of lead. I drew attention to the fact that it was found that there were always unreduced peroxide grains scattered through the plug, except on the surface where the reduction to sulphate was complete. What struck us most, when removing the plugs, was that the chemical action started at their edges, and then extended across their whole surfaces while also penetrating downwards between the

Mr. Robertson.

plugs and the grid, but it was only on the surface layer that the sulphation appeared complete, the lower and inner portions of the plugs being darker in hue, but when they were broken up it was evident that the chemical action did not take place uniformly throughout their mass. The lower and inner portions were darker than the upper and outer, while the necks of the plugs even at the end of discharge showed little or no visible sign of the formation of sulphate. This suggested the idea that they contributed very little to the action of the cell beyond serving as conductors, and I may here mention that many months afterwards Messrs. Lamb and Smith informed me that the cell which had been used for the experiments was working very satisfactorily, and apparently enjoying good health.

It appears to me that no very hard and fast conclusions can be deduced from these analyses, because with a more porous active material which exposed a larger surface to the electrolyte, I fancy that more of the peroxide would come into action before the layer of sulphate formed on its surface was sufficiently thick to prevent the penetration of the electrolyte, and this would of course make a difference in the relative proportions of peroxide of lead and lead sulphate found in the plate at the end of discharge. It might be thought that the colour of the product formed in the cell would afford some light as to its constitution, but this is not the case, for powders practically identical in hue with those obtained by grinding up the plugs were produced by simple mechanical mixtures of pure peroxide and sulphate of lead blended together in a mortar, and it does not appear possible that any chemical union could be effected in this process. Just as we find that the addition of a little sulphate to the peroxide alters its hue, so we find that a paste formed from this mixture has a lower E.M.F. than that afforded by a paste of the pure peroxide, and, as is well known, the latter yields a lower E.M.F. than the electrolytic. Mr. Desmond FitzGerald demonstrated this fact before a meeting of this Institution many years ago, and I also have repeated the experiment with pastes of varying composition, but I could not find that the lowering of the E.M.F. followed any definite law, and it appeared to depend rather on the effect of the lead strip used to support the paste than on the proportion of sulphate in the paste. In the case of electrolytic peroxide the oxide is practically welded into the lead support, but in the case of an applied paste there is no such perfect union, however thoroughly it may be rubbed and compressed into the lead, and so there is an opportunity for the formation of a couple between the peroxide and the supporting lead which lowers the E.M.F. due to the action of the peroxide paste and the opposing lead plate.

It has been stated that, if the peroxide is thoroughly screened from the action of the support, the chemical peroxide will give the same E.M.F. as is yielded by a cell which has reached its steady value. This screening may be effected by taking a long glass tube curved at one end, filling it with peroxide, and arranging it so that the curved portion just dips below the level of the acid, so that there is a good column of peroxide between the terminal of the cell and the level of the acid; but I have never been able to verify this statement for myself,

Mr. Robertson.

as I was compelled to abandon experimental work just after I had made a number of such tubes.

Professor Armstrong has referred to the subject of the formation of persulphuric acid and its function in the cell to which we drew attention in 1891, and which was subsequently noted by M. Darrieus about a year later. It therefore only remains for me to say that Mr. Wade has done a great service in insisting on the value of porosity in the construction of battery plates, and for giving us some term by which to measure it, and my remarks have been made more with the object of showing how little we know of what goes on in the cell than of disproving the very symmetrical theory which Mr. Wade has propounded; and I hope that he or some one else will follow up the theory of molecular compounds, and do for the salts of lead what Perkins has done for the hydrates of sulphuric acid.

Mr. Walker.

Mr. S. F. WALKER [*communicated*]: The paper is, in my opinion, one of the most valuable that has been presented to the Institution for some time. Notwithstanding the fact that a great deal has been done in the matter of accumulators, we are still wanting a large further progress to enable us to deal with the problems that are waiting for us. No one seriously doubts, for instance, that the automobile of the future will be electrically driven. Yet as we know, the way is barred, and other agents, such as petroleum, and even steam, are making far more headway, because of the uncertainty of the accumulator.

In my opinion, Mr. Wade has gone pretty well to the root of the matter in the remarks which he makes in the paper about the porosity of the active materials, and the diffusion of the electrolyte through those materials. One point he appears to have brought out very clearly: that it is useless to hope for increased storage capacity, or increased life, from an increase of the thickness of the active material. Another point that appears to me to be clearly brought out in the paper is, that the electrical connection between the active material and the supporting plate must be largely by means of the electrolyte. In fact it would appear that the supporting plate performs the same office that the negative (collecting) plate performs in the primary battery, viz., it collects the current from the active material, just as the copper or carbon plate does from the electrolyte, or from the depolariser. If this is so, the question arises, could not some other metal be substituted, in place of lead, for the supporting and collecting plates. I am aware, of course, that by introducing another metal you also introduce additional galvanic action; but is the case so formidable as it would seem at first sight? We have already a separate galvanic battery at each plate. Would the loss be much greater (would it be as great?) if, instead of lead collecting plates, with the inevitable lead-lead-oxide couple, we had some such metal as aluminium, some metal not readily attacked by sulphuric acid. If it could be arranged to have accumulators consisting of a light framework of such a metal as aluminium, or platinum, with a thin layer of active material deposited on it, by electrolysis, one of the difficulties of the problem of portable electric accumulators for *all purposes*—and the purposes to which such an accumulator could be put are very numerous—would have disappeared.

Mr. Walker.

Again, I am aware that the problem involved in the electro-deposition of a lead salt, upon aluminium, or upon platinum, is a very difficult one, but it appears to me that the possible gain is well worth the trouble. There is also, of course, the question of expense. If aluminium can be used, probably the extra cost will not be serious, if there be any extra cost. But all these things behave, often, so differently from what we expect, no matter how carefully we think the matter out, especially with a metal such as aluminium, whose working is comparatively unexplored, that one can only suggest lines of investigation. I will only say in conclusion, that in an electro-chemical investigation which I conducted, a short time since, many things were found possible that experienced chemists assured me were quite impossible, and that some results obtained with aluminium were somewhat startling, from their point of view.

Mr. Boyd.

Mr. W. Boyd [*communicated*] : May not the gradual drop in capacity of the negative plates of a battery be caused by electrolytic action in the cell due to the presence of acid impurities in the electrolyte? Observations I have made seem to confirm this. I think the action taking place is as follows :—Slight traces of an acid forming a soluble salt of lead being present in the electrolyte first of all attack the peroxide plate to form that salt. This is during the next charge electrolytically deposited on the surface and in the pores of the negative plate, liberating the acid, which again attacks the peroxide and dissolves a further portion. This action after a time, which depends on the amount of impurity present, closes up the pores of the negative plates, thereby decreasing the active surface ; the peroxidising of the plate and subsequent reduction restores the capacity, in consequence of the expansion that takes place during the oxidising and the contraction during the reduction making the plate once more porous. In some bad cases that I have seen, the electrolytic action has been sufficiently marked to produce a lead-tree formation on the surface of plates. The impurities present in the electrolyte may be derived from several sources ; such as the acid which is used for filling cells in the first instance, or afterwards for making up evaporation, not being absolutely pure, or because some acid or acid-forming substance used in the process of manufacture has not been removed before cells have been put into use.

[Owing to the lateness of the hour Mr. Wade was asked to reply to the discussion on his paper at the meeting on April 5th.]

The Chairman announced that the scrutineers reported the following candidates to have been elected :—

Members :

Richard Tetley Glazebrook, F.R.S.
Professor Henry Stroud, M.A., D.Sc.

Associate Members:

Alexander Adams.
Harold Leslie Dixon.
George Horley.
William Augustus Kemm.
Sydney George Leech.
Charles Lopdell.
Cecil Arthur Noton.
Henry Savage.
John Burrell Talbot-Crosbie.
Charles Turnbull.
Edward White.
William Scott Till Worthington.

Associates:

Edward Russell Clarke.
George Francis Carter Gordon.
Francis Moss Moody.
Charles A. Pulsford.
Ernest Smith Awmack Robson.
Tyson Sewell.
Francis Sydney Shaw.
Edwin Charles Smith.

Students:

Arthur Francis Turnour Atchison.
George William Selwyn Driver.
George Gordon Ede.
Francis Clifford Higgs.
Arthur Horace Jones.
Alfred Henry King.
Edmund Rycroft Verity.

The Three Hundred and Forty-fifth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 5th, 1900—Professor SILVANUS P. THOMPSON, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on March 22nd, 1900, were read and approved.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Foreign Members to that of Members—

Professor E. Mascart.

From the class of Associate Members to that of Members—

Ellis Herbert Crapper.

From the class of Associates to that of Members—

Marcus Stanley Chambers.

From the class of Associates to that of Associate Members—

David Alexander.
E. J. Brothers.
W. G. Clarke.
J. T. Cornish.
A. J. Hodgson.
A. B. Randall.

From the class of Students to that of Associates—

F. R. Bridger.
J. P. Trotman.
P. R. Wray.

Messrs. C. H. Rosoman and R. J. J. Swan were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Carré and Naud, Señor R. A. Echeverria, and the Italian Minister of Posts and Telegraphs; and donations to the *Building Fund* were announced as having been received from Mr. F. W. Clements, Major A. M. Stuart, R.E., Mr. H. J. Allen, Mr. J. C. Smail, Mr. J. F. Lister, Mr. A. P. McDouall, Mr. E. Manville; and to the *Benevolent Fund*, from Mr. A. H. King, Mr. C. Turnbull, and Messrs. E. Green & Sons, Limited, to all of whom, on the motion of the President, a vote of thanks was unanimously accorded.

The PRESIDENT: I have to announce that extra meetings will be held on May 3rd and May 17th, at the Institution of Mechanical Engineers, by the kind permission of the Council of that body.

I now call upon Mr. Wade to reply to the discussion on his paper on Battery Storage Problems.

Mr Wade.

Mr. E. J. WADE (*in reply*): Before replying to the various criticisms passed on my paper, I must thank members for the leniency with which they have received some of my views even when not agreeing with them, for I was painfully aware that in advancing new theories not supported by more direct experimental evidence I could not have complained had they been subjected to much more severe handling.

The first point I must deal with is the doubt expressed by Mr. Swinburne and Mr. Cooper as to the need for further attempts to explain what went on in lead cells. Has not the matter already been substantially thrashed out and stated in its simplest terms, and am I not merely setting up imaginary difficulties in order to knock them down with ingenious and complicated arguments? This question is most vital to the whole scope and purpose of my paper, for were the answer in the affirmative I should stand convicted of having most unnecessarily occupied the valuable time of this Institution.

Mr. Cooper thought that if secondary cells had only been used as primary cells there would not have been all this bother about them. Possibly not. As long as their employment in the engineering and electrical world had been limited to that of primary cells, the general statements already available might have been quite sufficient for all practical purposes, but I think we may rather reverse Mr. Cooper's dictum and say that if primary cells had been born secondary cells many of the accepted explanations regarding them would long ago ...ve had to be overhauled and far more explicitly stated.

... Swinburne considers that the discharge of a cell can be ex... far as the electrodes are concerned, in terms of the forma-

tion of normal lead sulphate, and that the cell's behaviour can in all respects be reconciled with this assumption. Mr. Wade.

Here we come to what is and always has been the crux of the whole matter, and I have stated in my paper the chief and, to my mind, fatal objection to that view. I will read the few lines I refer to:—

"Normal lead sulphate is probably quite irreducible if not unperoxidisable, in a dilute sulphuric acid electrolyte of the strength ordinarily used in storage cells, *provided all the materials are absolutely pure*, for the smallest traces of impurities make a remarkable difference in this respect. But however that may be, there is no doubt as to its being acted upon with extreme slowness, under the most favourable conditions in admixture with other materials of a more conductive nature, and then only with an excessive outlay of energy in proportion to the result obtained; whereas both the active materials can be brought back to their original states of lead and lead peroxide with great rapidity and the expenditure of very little more current than is theoretically necessary. This discrepancy, as well as the almost complete masking of other properties of the normal sulphate, can hardly be explained as due to its state of extreme subdivision and intimate admixture with unaltered active material, for under certain well-known conditions of treatment it does appear in full possession of its distinctive colour and with its non-conductivity and irreducibility aggressively in evidence."

Before writing that, I had carefully considered all the experimental evidence of which I have any knowledge bearing on the subiect, and I do not think I have said anything that cannot be justified. The most debatable point refers to the reduction of normal lead sulphate. Both Lord Kelvin and Dr. Lodge were unable to reduce it electrolytically. Then Messrs. Gladstone and Tribe obtained its reduction, and later on Mr. Swinburne also found that it would reduce. But meanwhile Dr. Lodge, aware of the results obtained by Messrs. Gladstone and Tribe, carefully repeated his experiments, and still he could not reduce the pure sulphate. I have myself several times tried to reduce it electrolytically, without success, but, as just mentioned, I have found this negative result may be very easily modified by the presence of impurities. I will reserve further remarks on this point for my communicated reply, for I do not think that the clearest proof of the mere possibility of reducing the normal sulphate would affect the main issue. Even granting that, it appears to me that all the evidence is against the possibility of the normal sulphate being either reduced or peroxidised with anything approaching the rapidity and efficiency with which these operations are performed every time a cell is charged, and I maintain that, if for no other reason, this alone would render it necessary somewhat to modify or to supplement the usual explanation.

At present we try to explain the reaction of lead with sulphuric acid as if it were an exactly similar one to that of zinc and sulphuric acid, whereas there is an essential difference between them. In the latter case the resultant compound is a soluble one; the molecules of zinc taking part in the reaction pass into solution and their relations with the remainder of the electrode are thereby entirely ruptured. But in

Mr. Wade. the case of lead, the sulphate being insoluble, the lead molecules do not acquire the same freedom of motion and are unable to change their position. This being so, it seems to me extremely probable that besides reaction with the sulphion ions in the electrolyte, they also still remain in feeble and unstable combination with other lead molecules in the active material, and this is what the view I have ventured to put before you practically amounts to.

I need hardly remind you that the question to be decided is not which is the simplest theory, but which is the true one. There is no use in sticking to a simple theory on account of its simplicity if it does not really explain the facts. At the same time, I do not think that my account of the cell's reactions, if properly looked at, is really more complicated than the one generally accepted. All I propose is, that for any given output, instead of saying, as we should in the case of a zinc electrode, that so many molecules have been fully converted into normal sulphate, we should say that the whole number of molecules in the electrolytic circuit have passed through a certain degree of sulphation.

I think, perhaps, by assuming for illustrative purposes, lead molecules of a specified constitution, and working out a formidable series of compounds on that basis, I have chosen a rather clumsy method of expressing myself and have obscured my real meaning. If I had merely given the general case in the form of an algebraical equation, it would probably not have appeared nearly so complicated.

Dr. Armstrong put the query as to whether my sulphated compounds really helped matters much because they had to be assumed of such very unstable constitution. No doubt in some ways it must appear something of a quibble to attach so much importance to the difference between an extremely intimate mixture and an extremely feeble compound, but all the same the two phrases serve as the basis for two entirely distinct lines of reasoning; and very important differences of physical structure and properties do sometimes result from most insignificant alterations of chemical equilibrium. As I have been somewhat reproached with introducing unnecessary complications into an extremely simple problem, I was very glad to hear some one who can speak with so much authority as Dr. Armstrong calling attention to the fact that there are other complications connected with the formation of lead peroxide and the changes occurring in the electrolyte, of which I have hardly taken any notice at all. This was simply due to my endeavour to leave out everything that did not directly bear on the special points I wished to bring before you, but it is as well we should be reminded how much obscurity still attaches to what is, after all, the fundamental action in a storage cell—the electrolysis of dilute sulphuric acid.

Mr. Hibbert has given several reasons for not considering the active materials to be in an allotropic condition. Of course, so far as he has obtained results opposed to those of Darrieus, he weakens the positive evidence in favour of allotropy, and, as is generally the case in all attempts to clear up these matters, we are left in the puzzling position of having to decide between conflicting data.

I do not think his other two reasons apply to the case. I certainly ould expect spongy lead precipitated from solution by zinc, to giv

the same E.M.F. effects as ordinary negative active material, for I believe lead obtained by all such processes to be in an allotropic state, and I do not think there is any electrolytic method, such as the one in question essentially is, by which lead can be deposited in a normal condition corresponding, for instance, with ordinary electrolytic copper. Mr. Wade.

As regards the comparison of the specific resistances of electrolytically and chemically prepared lead peroxide, I doubt the possibility of any conclusions bearing upon the question of allotropy being drawn from Dr. Shield's experiments on these substances in the form of compressed powders. The measurements were only incidental to an investigation carried out with quite another object, and I should say the results would vary with every difference in the degree of pressure to which the powders were subjected and the size of the particles of which they were composed; and also the precise electrolytic process by which the peroxide was procured. As it was, the results showed a difference in resistance of over 15 per cent., which might be construed equally well in favour of allotropy as against it; but had the difference been 50 per cent. or nothing at all, I should, under the circumstances, still attach no value to it.

I regret to find that the portion of my paper relating to the necessity for increasing the porosity of the active materials and the rate of diffusion into them had been somewhat misunderstood. After giving some definite figures to show how defective are the active materials of commercial cells in this respect, I go on to say: "As long ago as 1889 Messrs. Duncan and Wiegand called attention to some of the results that must ensue if proper diffusion were not provided for; and Messrs. Gladstone and Hibbert, in their communication to this Institution in 1892, also indicated some of the effects probably due to this cause. In the latter instance, however, they were considering the matter chiefly in its relations to the E.M.F.s of cells under various conditions; and I think it yet remains to be recognised how far-reaching are the consequences of defective diffusion, and how many of the faults and shortcomings of the cells may be attributed to it."

I thought that made my position in the matter quite clear, and I then proceeded to work out the whole case against insufficient porosity, indicating in what parts of the active materials and under what conditions the different effects occur. Mr. Hibbert was quite right with regard to the extract he read at the last meeting from Dr. Gladstone and his own paper of 1892, describing the effect of the weak acid in the pores on a cell's output and the production of abnormal compounds. Although considerably elaborated, and with what I believe to be some important modifications, its substance does appear again in my paper, and it is essential to my object that it should do so, for I am there endeavouring to collect the previously scattered and sometimes indefinite statements and embody them all in a precise and definite whole; but I do not think there is anything to suggest that I imagined I was the first person to study porosity and diffusion. As a matter of fact, the paragraphs quoted by Mr. Hibbert are in their turn covered by a still more general statement of the same points made by Mr. Swinburne in the *paper he read* before this Institution in 1886.

Mr. Wade.

There is a second point in my paper which appears to have been still more completely misapprehended, and that is where I refer to the gradual loss of capacity so often experiencd by negative electrodes, which I said had never yet been satisfactorily explained. Mr. Hibbert pointed out that this was due to the discharge or sulphating of the spongy lead by local action with the electrolyte, and he gave quite a number of authorities who had previously mentioned the fact. I suppose I ought to have made myself clearer, but it never occurred to me that I should be thought at this late period to be still trying to explain that simple and well-understood effect. The loss of capacity I referred to was one spread over a much longer period and much more permanent in its nature. It is usually supposed that negative plates will outlast two or more sets of positives. Where the conditions of working are severe, and the life of the positives for this or other reasons short, such is generally the case; but if the battery has been well treated and the positives have lasted a long time, it does not usually follow.

If after five or six years the capacity of a battery has fallen very low, and while the negatives are to all appearances in as good condition as when first put in, the positives have shed most of their active material and are beginning to break up, it seems obvious that the fault must lie with the positives; but when these have been replated, the capacity is often found to be not a whit improved, and finally the negatives have to be renewed also. This is a very usual occurrence, and illustrates the phenomenon I was really alluding to. Without any loss of active material, the capacity of all negatives of whatever type steadily decreases in the course of time. In some cases it will be an extremely slow process; in other cases, perhaps certain types or even only certain batches of cells, but without any apparent reason, a large proportion of their capacity will be gone in a year or two, and when a manufacturer has to guarantee a battery still to give a specified output at the end of a certain time, he is often more anxious about the negatives and the margin of capacity they should or do possess than he is about the positives.

The late Mr. Frank King was, I believe, the first to call public attention to this behaviour of negatives in the course of the discussion on Professor Ayrton's paper on "The Chemistry of Secondary Cells," in 1892; and he pointed out that it was accompanied by shrinkage of the active material. The loss of capacity may, as Mr. King seemed to think, be chiefly a matter of loss of contact between the active material and its support; but even then it would only be a result of the shrinkage and not its cause. The effect is certainly not due to sulphation, and I am inclined to ascribe it to some molecular change of structure. In this connection it is curious to note that the capacity may sometimes be restored by reversal if the electrodes are of a kind that satisfactorily admits of such treatment.

I was relieved to find that the most trenchant of Professor Ayrton's criticisms were directed at the Electric Cab Company and not at myself. He put, however, two questions. The one was why the potential difference of a cell rose during the first few minutes of a

discharge following upon a prolonged rest on open circuit. I have often puzzled over the curves showing this effect, but have never been able to hit upon an explanation which was at all satisfactory, for two reasons; firstly, there are other curves in the series from which those in question are taken that show no rise of potential difference on discharge after equally prolonged rest; and secondly, it takes several discharges, *each following directly on the previous charge*, to wipe out the rise and restore the curve to its normal shape. Mr. Wade.

The other question was, how so much more energy could be put into a cell by charging at constant potential instead of at constant current, especially having regard to my view that the higher the charging current, the greater would be the liability for the inner layers not to receive their proper share. The two certainly do not at first sight appear to fit well together, and although in the absence of fuller data as to the effects of extremely high charging rates it is impossible to do more than hazard an explanation, I think it may probably be somewhat as follows: I have assumed in my paper that the outer surfaces of the active materials work, under all conditions of charge and discharge, in an electrolyte of the same, or almost the same, strength as that contained in the main body of the cell. I think this must hold good for all ordinary charging rates, and if so, an unequal distribution of the current on the lines I have indicated necessarily results. But when such relatively enormous currents are used as flow during the first period of a charge at constant potential, the acid will be released in the pores with such extreme rapidity that the bulk of the electrolyte will, so to speak, be pushed back from the electrodes and *every portion* of the active materials will be surrounded by much stronger acid. If this happens, although the whole potential difference of the cell rises rapidly, the distribution of the current will be much more uniform; and by the time the current has dropped to what would, under the usual conditions, be considered a high charging rate, the recharge of the inner layers of active material will be too nearly completed for the unequal distribution that may then set in appreciably to affect it.

[*Communicated.*] With further reference to the question of the electrolytic reduction of lead sulphate in sulphuric acid, I am inclined to think that the discrepancies between the results previously obtained may possibly have been due to its not always being perfectly pure. The method most probably adapted, as being the simplest and readiest, to prepare lead sulphate for laboratory tests would be to precipitate a solution of lead nitrate or acetate with sulphuric acid and then wash it thoroughly. Now lead sulphate is not at all an easy substance to wash properly, and my experience has been that after the washing is apparently quite complete, it still retains perceptible traces of nitrate or acetate in combination with it; and it is just such small quantities of impurity that I find make all the difference in its reduction. Possibly a very prolonged washing with boiling water would entirely remove them, but unless sulphate prepared by this method were subjected to ignition before using it, I should be very doubtful as to its purity; and errors due to this cause might easily creep in without one were specially on their guard against them.

Mr. Wade.

What appears to me to be the real factor which determines the reduction of lead sulphate and enables its electrical non-conductivity to be overcome, is not its degree of contact with the electrode, but its degree of solubility in the electrolyte. This was substantially the conclusion arrived at by Dr. Lodge, as may be seen by reference to an interesting letter of his which appeared in *Nature* for October 19th, 1882. The experiments there described were made with lead sulphate prepared from the carbonate, so that in this instance all chance of errors due to the cause just suggested would be eliminated.

Lead sulphate can certainly be peroxidised even where it cannot be reduced, but then the conditions existing at the anode and cathode are not the same. With sulphuric acid solutions of almost every strength, some small quantity of persulphuric acid will be produced at the surface of the anode, and this probably reacts slowly with the lead sulphate, converting it into persulphate, which then immediately passes over to peroxide.

The strength of the electrolyte used is therefore a very important matter, because it has a direct relation both to the solubility of the sulphate and to the amount of persulphuric acid that will be formed, but no data on this point appear to be given in any of the published investigations.

A further attempt to determine the conditions under which lead sulphate can be reduced and peroxidised would be well worth making; and if special attention were given to the purity of the materials and the strength of the electrolyte, I believe there would not be much difficulty in definitely ascertaining them.

The President.

The PRESIDENT: I have to ask you to accord a hearty vote of thanks to Mr. Wade for his paper, which is one of the most important papers on the subject of accumulators that has been brought before this Institution or any other scientific body for some years.

Carried by acclamation.

THE ELECTRICAL EQUIPMENT OF SHIPS OF WAR.

By C. E. GROVE, Member.

INTRODUCTORY.

This subject, already a great one, is rapidly growing, and the use of electricity on ships of war is yearly being extended in all the navies of the world. While, therefore, the bulk of the paper records what has already been accomplished, regard has been paid throughout to certain imminent developments which in many departments o'ershadow present-day practice.

The methods followed in the English Navy have to so

large an extent constituted a guide and pattern to the world, that the basis of the present paper lies naturally in British Admiralty practice. In certain navies, however, important departures from British practice now exist, and tend to become more marked with the flux of time; some of these are referred to hereafter. The author's intention has been entirely to avoid administrative and tactical questions, and to treat the subject solely from the point of view of an independent electrical engineer. In British warships, and in ships built in this country for foreign Governments, the constructive work falls into three main divisions, dealt with respectively by the "shipbuilders," the "engineers," and the "ordnance contractors"; and part of the electrical work falls into each division. In the present paper this distinction is ignored and the electrical equipment treated as a unity.

PART I.

GENERAL EQUIPMENT.

DYNAMOS.

The first important step in the use of electricity on board ships of war dates from the introduction of the dynamo. In 1876 a Wilde alternate-current magneto machine, belt-driven, was installed in H.M.S. "Minotaur," to work a searchlight projector. This machine gave place to the continuous-current Gramme dynamo, so soon as the latter had assumed practical form; and this again was superseded in due course by the two-pole drum-wound direct-coupled compound steam dynamo which until about 1895 was standard in our navy. The size of unit varies in our navy by steps of 100 amperes from a machine giving 100 amperes in the case of torpedo boat-destroyers, small gunboats, and the like, to a machine of 600 amperes as now used in all modern battleships and large cruisers. The standard voltage is 80 in all cases, this having been settled long ago as a convenient compromise between the pressure required for working searchlights and that giving the best efficiency in the ordinary electric-light circuits. With the growing demands for current, this low voltage is becoming increasingly inconvenient—a matter which will be referred to again further on. For all sized

[illegible] Until this interference had been actually proved to be due to the dynamos themselves, it had been attributed to induction from the currents in the wires about the ship; but it was found that their action was much less important than the direct influence of the dynamos. With an ironclad machine the stray magnetic field is reduced to one-half, or less, of what it is with an ordinary open-type machine, the stray field from the magnets (provided the machine is liberally designed as regards the mass of iron) being almost nil, while the leakage of magnetism axially along the armature shaft is greater.

The chief difficulties in designing ironclad dynamos arise in designing to a minimum weight and in providing adequate ventilation. Figs. 2 and 3 show an ironclad dynamo of the author's design in which thorough ventilation is secured by the device of coring slots through the bottom, sides, and ends of the magnet castings. The weight of an ironclad dynamo is greater by 50 per cent. to 75 per cent. than that of an ordinary Admiralty open-type machine of the same output, which reason has led to the ironclad type being superseded by an open four- or six-pole machine, which, on the whole, provides the best combination of good venti-

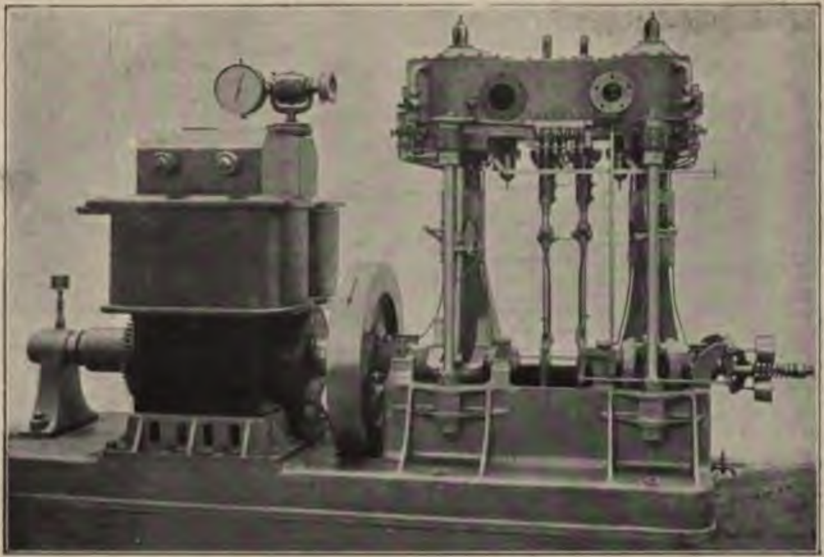
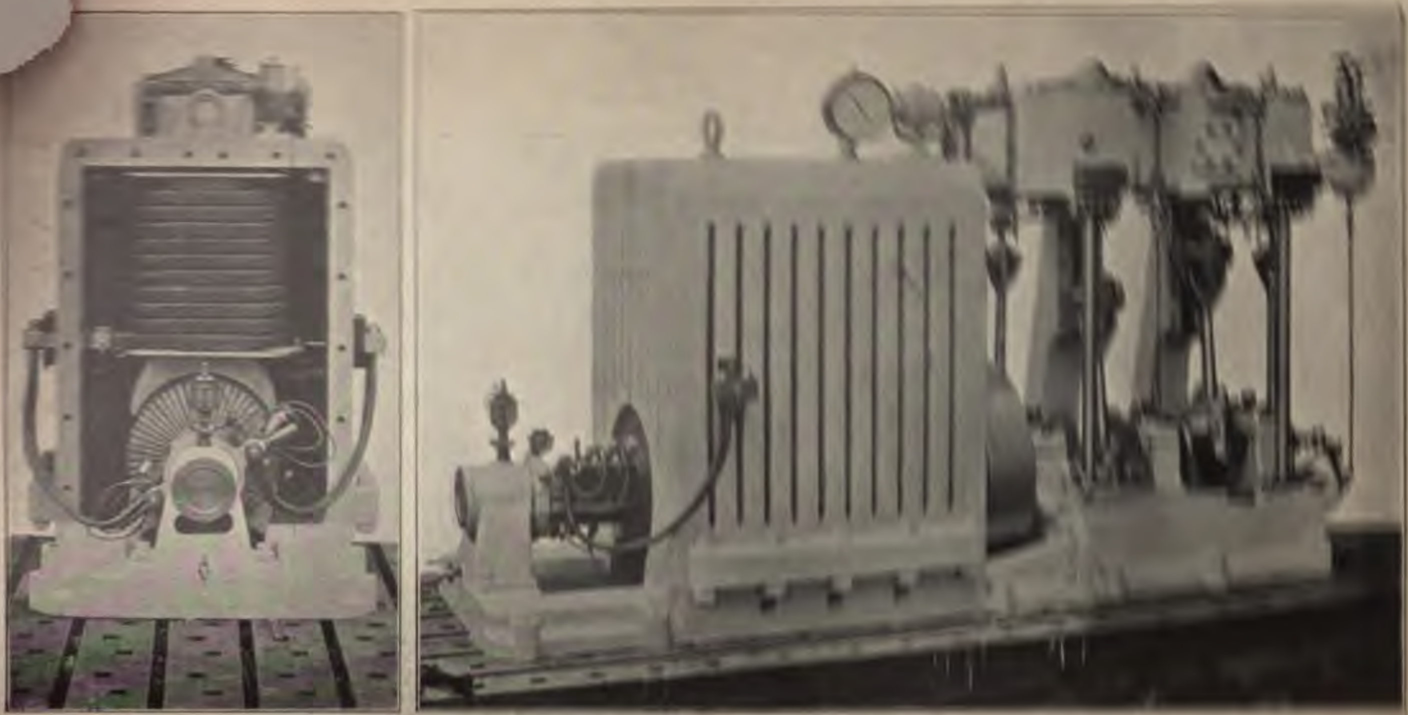


FIG. 1.—Admiralty Pattern 2-pole Steam Dynamo (Siemens Dynamo and Thornycroft Engine).



FIGS. 2 AND 3.—"Ironclad" Dynamo (Thames Iron Works).

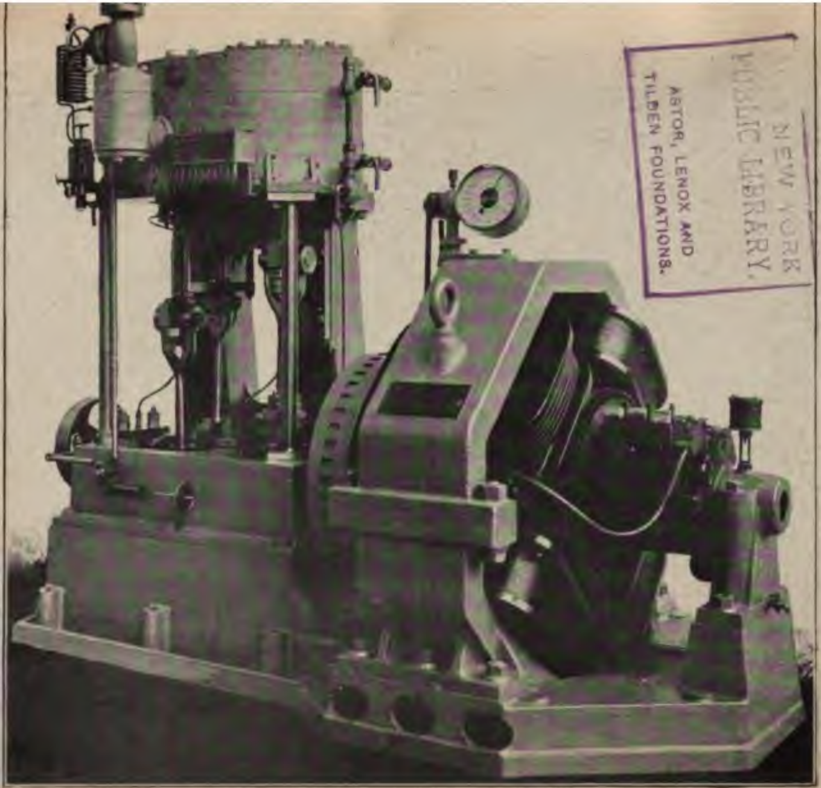


FIG. 4.—Modern Admiralty Multipolar Generator (W. H. Allen, Son & Co., Bedford).

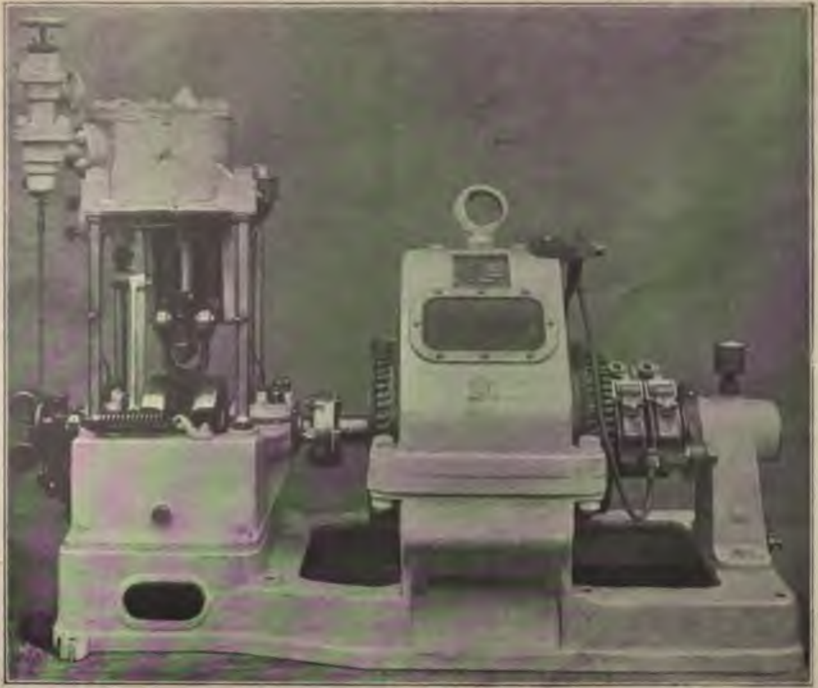


FIG. 6.—Vedette Boat Steam Dynamo, 6 k.w. (Thames Iron Works).

lation, minimum external leakage and accessibility of parts. Fig. 4 shows a recent 600-ampere Admiralty set, by Messrs. W. H. Allen, Son & Co. Most modern Admiralty dynamos have slotted cores. The total weight of such a set is about $6\frac{1}{2}$ tons, of which the armature represents about $1\frac{1}{2}$ tons.

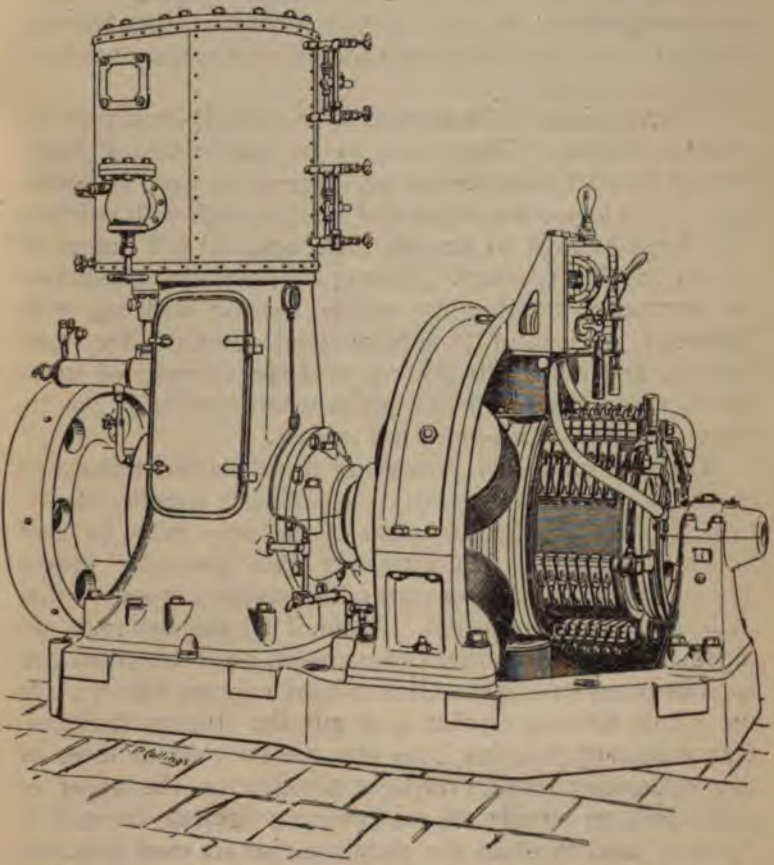


FIG. 5.—United States Navy Generator, 50 k.w. (General Electric Co., Schenectady).

The United States Navy usually employs a four-pole machine, their largest units being of 50 kilowatts at 80 volts at 400 revolutions per minute. The temperature limit is, however, 50 degrees Fahr., which involves a heavier dynamo than the British for the same output. Fig. 5 shows such a

set constructed by the General Electric Company of Schenectady.

By way of contrast to these large machines, a small steam dynamo (Fig. 6) may be mentioned which was recently designed by the author and fitted into 40-feet and 56-feet steam pinnaces for the Russian Government for working searchlights. In this particular case the required output was 60 amperes × 65 volts at 500 revolutions per minute, though the set has a maximum output of 6 units, on a total weight of 12 cwt.

Steam engines of the open type are usually employed for dynamo driving. They have to be constructed strongly enough to work with the full steam-pressure from Belleville boilers (275 to 300 lbs. per square inch), though with cylinder areas large enough to furnish their nominal full output at 150 to 200 lbs. pressure. Among the essential conditions for successful working are ample bearing surfaces, with thorough lubrication to ensure cool working for long periods, and ability to get rid of large volumes of water which come over with the steam when auxiliaries on the same range of steam-pipes are started.

The importance of preserving the dynamos unharmed in war is so great that at least a sufficient number of sets to supply all the fighting parts of the ship must be kept under protection. Unfortunately this generally means placing the machines in a warm, ill-ventilated space, so that their durability is impaired. Again, if all the dynamos are together, an injury to the compartment, or to the steam and exhaust pipes serving the electric-light engines would place the whole *hors de combat*, and put the ship in darkness. Our Admiralty practice is to put one of a set of three or four dynamos in some daylight position on the upper or main deck to supply all the ordinary lighting current in "peace," and to place the dynamos that are used in action below the water-line. Nations differ as to the advisability of doing this, the control being certainly less convenient when the machines are in separate places. The United States Navy place all the dynamos in one compartment. The Japanese divide the dynamos between the fore and aft auxiliary machinery rooms, but keep them all under protection.

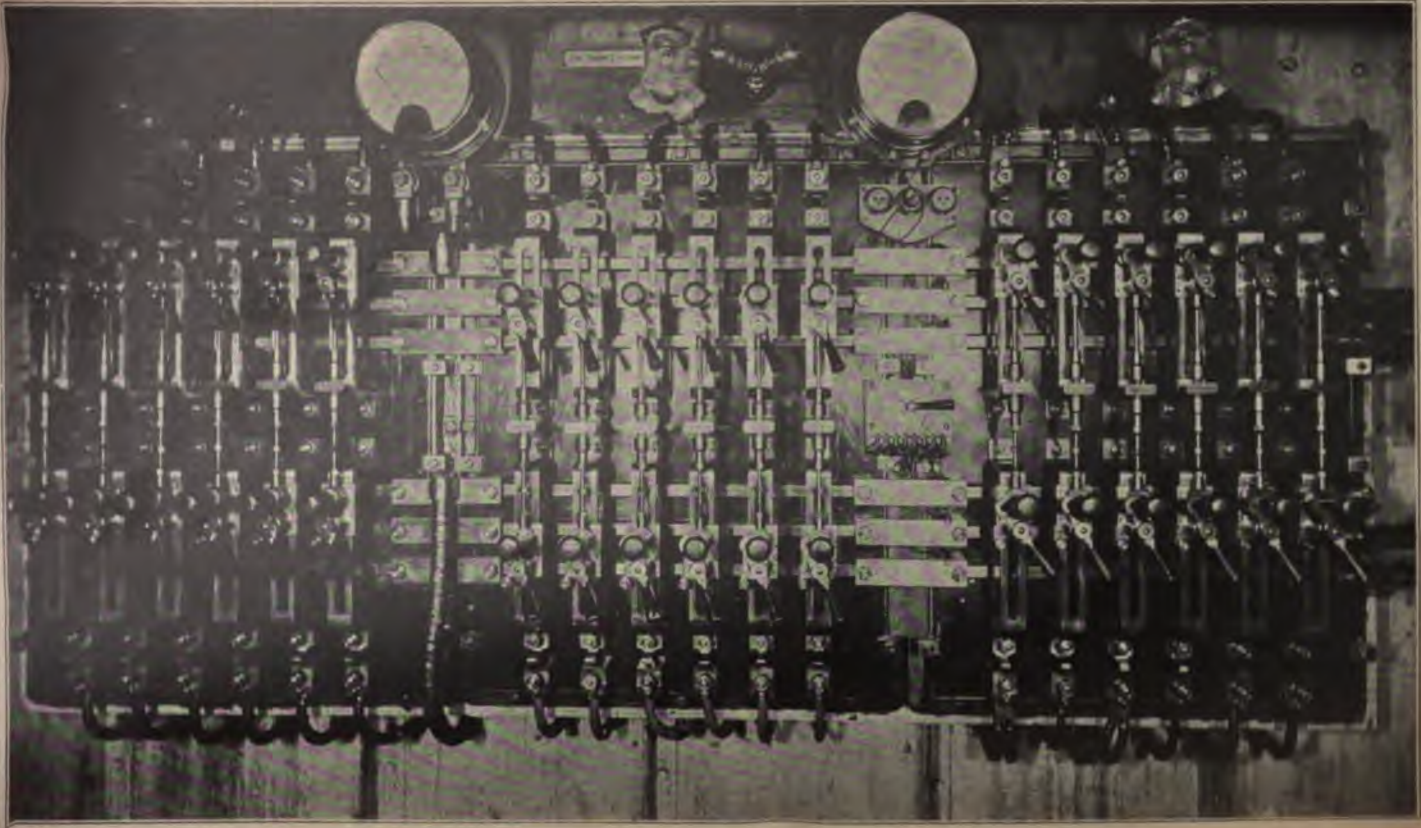


FIG. 7.—Admiralty-pattern Switchboards, as fitted in H.I.J.M.S. "Shikishima."

SWITCHBOARDS.

This standard British Admiralty pattern switchboard consists of a slate or slates carrying horizontally upon them a series of omnibus bars, connected severally with the

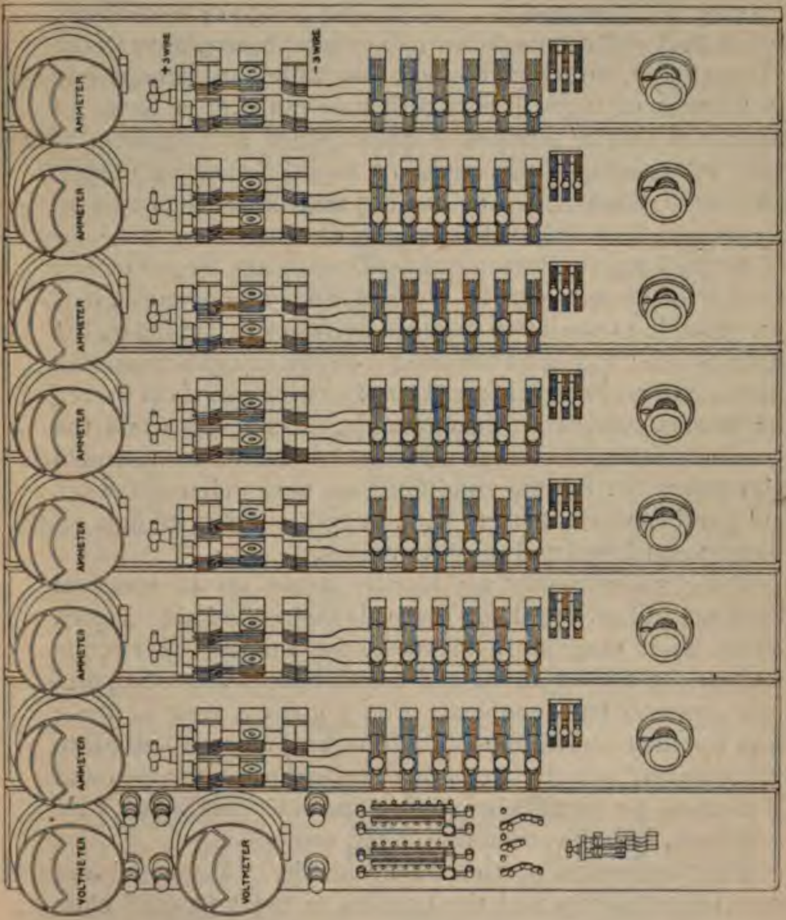


FIG. 8.—Main Generator Switchboard, U.S.S. "Kearsarge" and "Kentucky."

positive and negative terminals of the dynamos; and bridging over these, a series of vertical slotted bars leading through fuses to the circuits, and carrying sliding contact plugs which can be pressed down so as to make contact on the top and sides of the omnibus bars, being locked in the "on" position by a spring handle, and maintained in the "off"

position by the action of an internal spiral spring, which also gives a quick break. The switchboard has the merit that all the current-carrying parts are on its face, and it is fairly compact; but the method of making electrical contact leaves much to be desired, and the switch parts consist of a number of components which give complexity and add to the cost of maintenance. The present design of board grew out of that older type known to telegraph engineers as the "Umschalter," in which contact was made between any one of a series of vertical bars and any other of a series of horizontal bars by screwed or coned plugs uniting them at their intersection; this style of board failed in service because of the practice of making and breaking circuit on the plugs, which led to their speedy destruction.

In the English Admiralty board, while any circuit or any number of circuits can be worked from one dynamo, it is not possible to work two or more dynamos in parallel on the same circuit; and in transferring a circuit of lights from one machine to another, it is necessary to extinguish them during the process, which is objectionable. Time was when the parallel working of compound wound dynamos was attended with difficulty; but the conditions are now well understood, and parallel working is, in fact, in successful operation on many ocean liners and in other navies.

These switchboards are usually made up to standard drawings and arranged for three dynamos and six circuits. When, as is commonly the case, the number of circuits exceeds six, one or more additional boards are fitted, and their dynamo bars coupled. Fig. 7 gives a view of three such boards coupled in position on the Japanese battleship "Shikishima," which carries three 600-ampere dynamos and 18 circuits, six circuits supplying incandescent lights, four projectors, and the remaining eight, motors.

The battleships of the "Formidable," "Duncan," and more recent classes and the cruisers of the "Drake" class will carry four 600-ampere dynamos, usually running at 400 revolutions per minute, and a large number of circuits, some of which will supply current to powerful motors. The design of switchboard described above appears to be quite unsuitable for such installations.

The Cardew hot-wire voltmeter and the Siemens torsion *spring* ammeter are the instruments chiefly to be found on

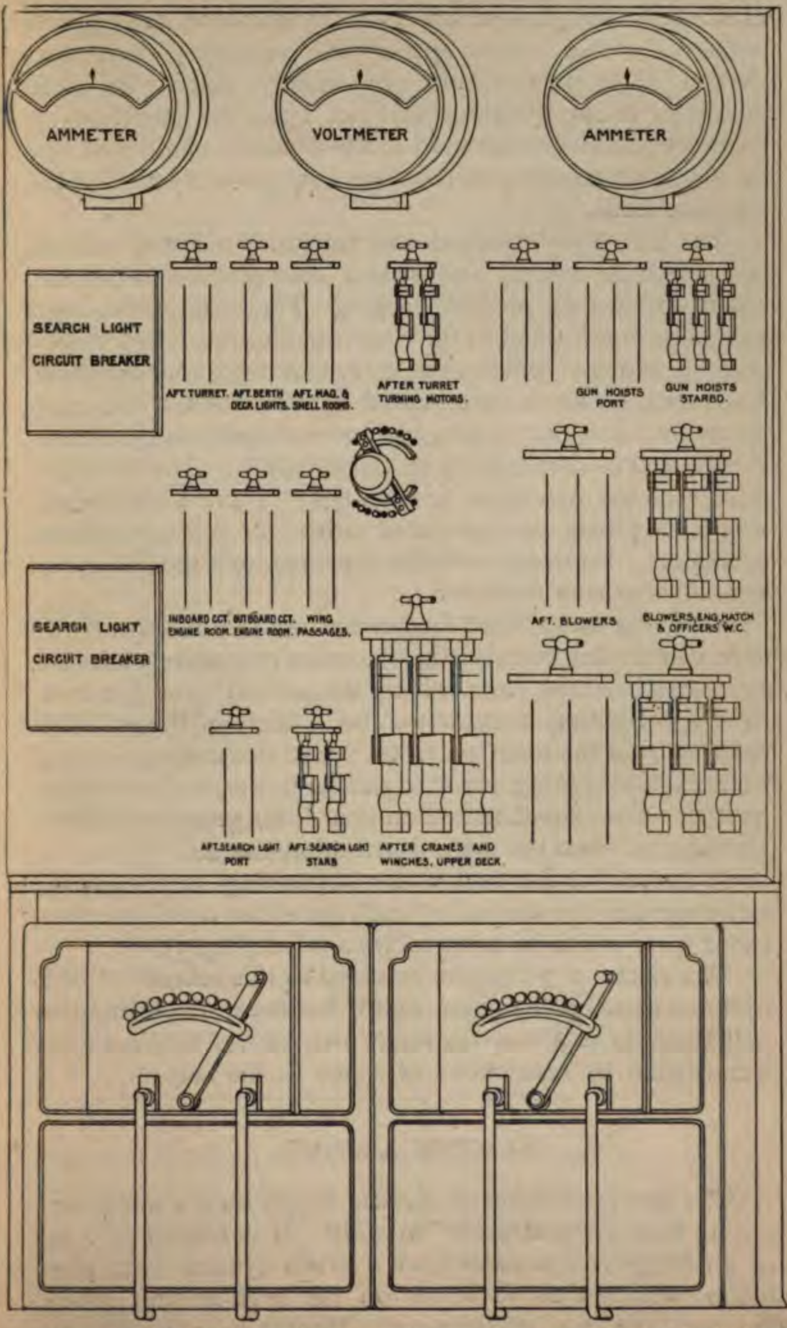


FIG. 9.—*Distributing* Switchboard, U.S.S. "Kearsarge" and "Kentucky."

H.M. ships, though these are no longer standard, having been replaced by dial instruments of the well-known Evershed pattern. The instruments are usually placed in close proximity to the dynamos, and not upon the switchboard. Circuit breakers are not used in the dynamo circuits of our navy, though double-pole fuses are now generally fitted in the machine leads.

The U.S. Navy standard switchboard is planned with its dynamo bars vertical and circuit connections horizontal, and is designed for parallel working. Fig. 8 shows the main generator board fitted in the recent battleships "Kearsarge" and "Kentucky," which each carry seven 50 k.w. dynamos. Each dynamo bar is surmounted by its ammeter and main throw-over switch. A panel at one end contains the instruments used in common by all the dynamos. The field terminals of the machines are brought to the switchboard, where they may be connected either for self or separate excitation. Equaliser switches are fitted on a separate panel in another part of the room.

From the main board feeders are run to three three-wire main distributing boards (Fig. 9) located respectively forward, aft, and amidships, from which the several power, searchlight and lighting circuits are run. Each of these boards receives from the main generator board five cables, a pair of "outers" for lighting, a similar pair for power, and a common neutral. Four sub-distribution boards for groups of motors are supplied from the main distribution boards.

A circuit breaker and a short-circuiting switch for the series winding are carried by each generator on the terminal board from which its main cables are led (Fig. 5).

The electrical principles involved in this scheme of connections seem, in the main, right; but the multiplication of switchboards is a bad feature, which is said to have been necessitated by restrictions of space in the ship.

Electric Lighting.

The first installation of electric lamps on a warship was put in H.M.S. "Inflexible" in 1881. It consisted of a set of arc-lamps run in series from a Brush dynamo with glow lamps arranged 18 in series on the high-tension mains. The arc-light has disappeared. Modern war vessels are

usually too much subdivided and have too little headroom to justify the use of arc-lamps, although these are again becoming somewhat common on merchant vessels. The parallel glow-lamp system became standard practice almost as soon as it was introduced, and the number of lamps

		FITTINGS															CIRCUITS					
DECKS	CIRCUITS	BULKHEAD	PENDT GUARDS	BRACKT "	PENDT CABIN	BRACKT "	PENDT SPECIAL	HAND	TABLE	BUNKER	PEDESTAL	SIGNALS	PILOT	MAGAZINE	YARD ARM	TOTAL FITTINGS	FORWARD	MIDSHIP	AFTER	STORE	ENGINE ROOM	MAGAZINE
ABOVE BRIDGE	AFT							1				1			8				10			
	FORD							1				9			8		18					
BRIDGE	AFT	3	2		2			3			3								13			
	MID										3							3				
	FORD	3	2		2						5	2					14					
UPPER	AFT		8	8	5	2		2	2										27			
	MID		28															28				
	FORD		10	9				1									20					
	ENG			11																	11	
MAIN	AFT		18	1	27	19			12										77			
	MID	36	35	6				2										79				
	FORD	15	10	5	5				1								36					
	ENG			12																	12	
MIDDLE	AFT		14	9	6	23													52			
	MID	18	22	1						19								60				
	FORD	19	7	11										3			40					
	ENG			11									1								12	
LOWER	FORD	1	2				2	2									7					
	STORE	5	42	25			8	10	1											91		
	ENG	2	9	26				8		14											59	
PLATFORM	STORE	2	32	13			1	13												61		
	ENG	6	27	52				2					2								89	
	MAG													44								44
HOLD	STORE		4				6							6						16		
	ENG		6	2				2													10	
	MAG													38								38
TOTALS		110	278	202	47	44	17	47	16	33	11	12	3	91	16	927	135	170	179	168	193	82

FIG. 10.—Schedule of Electric Lighting, H.M.S. "Albion."

employed has been steadily increasing. Thus, in the battleship "Colossus," fitted in 1884, 350 lights were installed; in the "Blenheim," first-class cruiser fitted in 1890, 525 lights were installed; the "Majestic" class of battleships, fitted in 1896, carry between 800 and 900 lamps; the "Albion" and her sister battleships of the "Canopus" class, just com-

pleting, carry about 950; the "London" and "Duncan" classes of battleships now building will carry from 1,000 to 1,050 lamps, while the first-class cruisers of the "Drake" and "Monmouth" classes now building will carry approximately 1,000.

It is usual to arrange the electric lamps in six circuits, one circuit being exclusively devoted to engine and boiler rooms, one to magazines, one to the central citadel, one to the crew spaces forward, one to the cabin spaces aft, and one to the stores and machinery rooms below the belt deck. It is desirable to have separate circuits for those portions of the ship which are protected by armour, rather than to mix up the lighting of protected and unprotected portions, though this is by no means generally done. A schedule showing the arrangement of lamps, fittings, and circuits on H.M.S. "Albion" is given in Fig. 10. In the U.S. Navy the lamps are arranged on two main circuits, known respectively as the "battle" circuit, which includes the lighting of all parts of the ship occupied in action, and the "lighting" circuit, which includes those parts where general illumination is required for ordinary purposes. Feeders running from the switchboards connect to the respective circuit net works through junction boxes. At "general quarters" the ordinary lighting circuits, which include all the exposed lights on the upper decks, are disconnected at the switchboards. This arrangement prevents stray light shining out-board.

Lead-covered cables and wires, first introduced into the Japanese cruiser "Naniwa-Kan," built at Elswick, are universally used in our navy, and the insulation is now vulcanised india-rubber in all cases. For single lamps a pair of 1/16 wires are employed; stranded wires which group the sets of lamps through fuse-boxes up to the circuits are universally composed of multiples of single 20-wire, the standard sizes being 7/20, 11/20, 15/20, 30/20, 60/20, 80/20, and 150/20; while for dynamos and heavy motor circuits 350/20 and 550/20 are employed. The current density is usually a little below 1,000 amperes per square inch, which ensures in the lengths dealt with a very moderate voltage drop. The present mode of fixing the wires and cables is to attach battens of teak to the bulkheads and to run the wires side by side along the teak under brass cleats or saddles. Thus all the wires are visible. According to Admiralty specifications,

steel battens may be used as an alternative to teak, but they would be much heavier, and the author is not aware of any ships so fitted. The introduction of these teak battens into our navy took place but a few years ago, and the step appears to have been quite a retrograde one. The employment of wood allows of fewer holes being drilled in decks and bulkheads than would be otherwise necessary, but the aggregate cost of the wiring work is considerably enhanced, useless weight is worked into the ship, and the danger of fire increased. The Japanese have in their latest battleships had the cables and wires attached directly to the decks and bulkheads, dispensing with backings, except where necessary for the heaviest runs or as packing to carry heavy runs of the larger cables over obstructions such as flanges of angle-bars, rows of rivet-heads, and the like. This makes a very substantial and satisfactory job. The practice in the U.S. Navy very much resembles land practice. Lead-covered wires were employed at one time, but it is said that the quality of the lead and of the insulation was such as to give trouble, and to cause them to revert to the old system. In their latest ships they have run braided wires in wood mouldings in cabin spaces, and in iron-pipe or conduit in machinery spaces; while in the crew spaces and in some of the fore and aft runs, the wires are supported below the decks on porcelain insulators, and protected by thin iron guard-plates put over them. None of these methods appears to be so safe or so thorough as the British Admiralty method of lead-covered cables closely packed together, and visible and accessible throughout their length.

Watertight Work.

Where the wires go through watertight bulkheads or decks, of course the bulkheads and decks must be made watertight behind them. Until recently, the method of making the cables watertight at the decks consisted in providing a length of iron tube lined with fibre, with a stuffing box and gland at the top end, by means of which an india-rubber packing was screwed down upon the cable; and similar glands were used where the cables passed through bulkheads. One disadvantage of this arrangement was

that where a number of cables and wires had to be dealt with, a considerable amount of space was taken up by these pipes in order to provide room for spanners to work in tightening up the nuts. A simple, compact, and effective method is as follows: Two pieces of wrought-iron plate are drilled with holes slightly larger than the size of the cables that are to go through the bulkhead; similar blocks of india-rubber about half an inch thick have holes formed in them just the neat size of the cable; the bulkhead is drilled with clearing holes; a slab of rubber and an iron plate are placed on either side of the bulkhead, the cables are drawn through, and then the plates screwed up tight. By this means pressure is put upon the rubber, which tends to make the holes through which the cables pass smaller, so that the cables are gripped, and the holes are left watertight. This arrangement was used by the author throughout the Japanese battleship "Fuji" both for decks and bulkheads. Fig. 11 shows a grouping of cables through such glands at the watertight bulkhead alongside the entrance of an ammunition passage. Many ships fitted at Portsmouth have rubber packed plate glands, though these are fitted only on one side of the bulkhead.

A new arrangement (Fig. 11A) was introduced by the British Admiralty in 1898. Brass glands of tubular form screwed to take a nut at one end, and having central holes, previously tinned, about one-eighth inch larger in diameter than the cable intended to pass through, are inserted in the bulkheads and made watertight on the iron by means of red lead. The lead-covered cable is drawn through, and its tape stripped back to bare the lead at the gland, a split tinned ferrule is then inserted to fill the clearance space around the cable, and the whole is then sweated up solid by means of a blowpipe. This is a rather tedious method until the men get accustomed to it, and there is some danger of overheating the insulation unless care is used; once the cables are tightly drawn through and sweated up, they have a neat and solid appearance, but they cannot be drawn back, and when repairs become necessary, it seems likely that the cables will have to be cut, which is a great disadvantage.

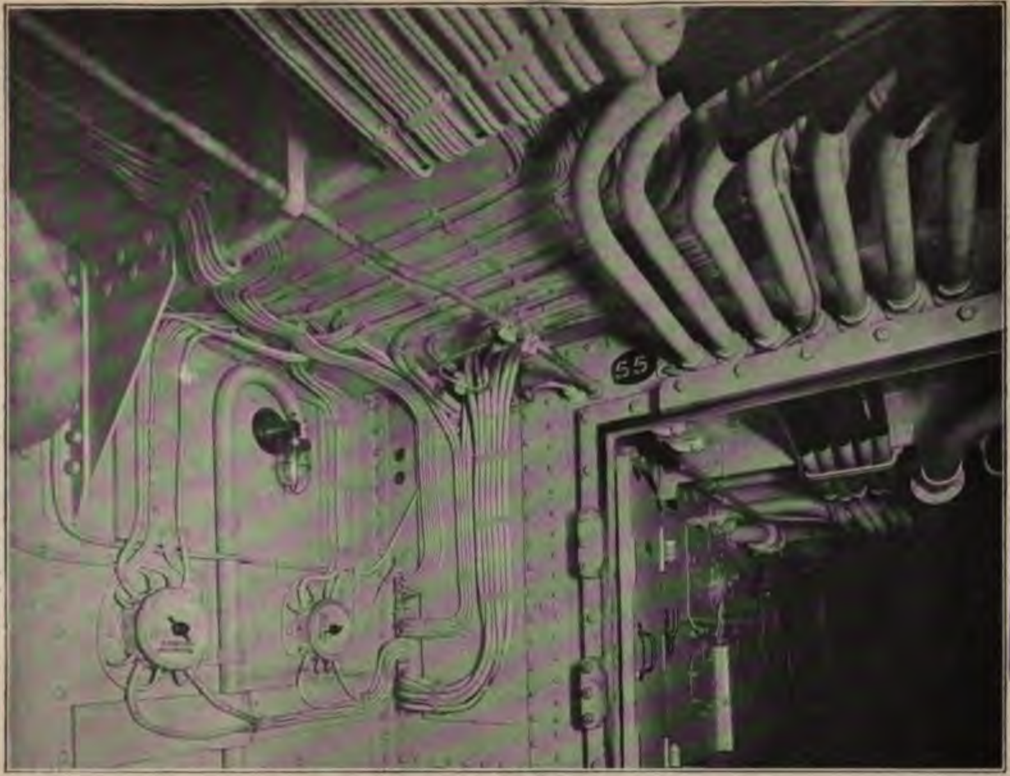


FIG. 11.—Cable Work at entrance to an Ammunition Passage, showing Plate Watertight Glands,

FIG. 11A.—Cable Work behind Switchboard, showing Tubular Watertight Glands.

Distribution System.

The main circuit cables from the switchboard pass, in the case of the heaviest circuits, through "junction boxes," into which they split usually into two branches protected by fuses. Each of these branches then passes through a series of "section boxes," which are circular watertight boxes containing a switch and four pairs of terminals for the attachment of fuses and the branching of cables. Each of the four pairs of cables running from a section box terminates in a "distributing box," which is a similar box

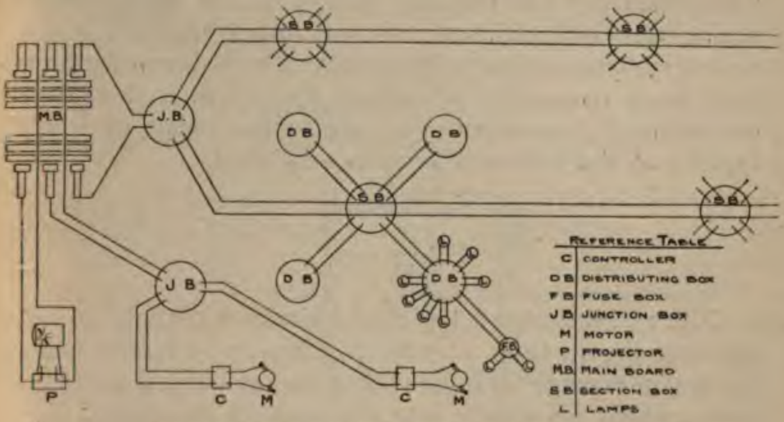


Fig. 12.—Diagram of Admiralty Distributing System.

to the section box and contains fuses and a double-pole switch. From each distributing box eight pairs of wires are taken, each pair leading direct to the terminals of one lamp. Fig. 12 illustrates the arrangement. As explained in the next section (p. 544), no lampholders, properly speaking, are employed. This "distributing-box system" was introduced into British warships about 1892. It is a modification of a method previously developed and used in wiring hotels, blocks of mansions, and such like places. Its advantages are that it enables the electric-light system to be entirely laid out without any joints or branches in wires, thus dispensing at once with what is usually an important source of trouble. In the event of any part of the system becoming injured, it can at once be switched off at the nearest distributing or section box, and the working of the system in general is not interfered with. The system allows

[illegible] completely watertight than [illegible]. The lead covering [illegible] enable the wires [illegible] then sweated [illegible] watertight with red-lead pack- [illegible] employed except [illegible] employ single-light [illegible] fittings for all lights except [illegible] magazines, which are controlled [illegible].

[illegible] universal. H.M.S. [illegible] British ship in which single [illegible] and this was soon converted. Con- [illegible] the outer conductor earthed. [illegible] for warships, but they [illegible] readily to the repair of small [illegible] employed.

FITTINGS.

Fig. 1, on Plate [illegible], is a typical Admiralty watertight fitting, showing the method of wiring. The lead-covered wires are drawn through an india-rubber washer pierced with two holes, which fits tightly into the neck of the fitting, thus excluding moisture; the lead and the insulation are then stripped back, and the bare wires led through holes in a slate disc which forms a separator; no lampholder, properly speaking, is used, but the ends of the wires are turned back with pliers to form hooks, and on to these bottom loop lamps, having twisted spiral platinum loops, are hung. Loop lamps are used because they best stand vibration and shock due to gun fire. But this method of wiring is capable of considerable improvement. If the hooks in the wires are not properly formed and are not of exactly the right length, bad contact and sparking result and the wires are burnt. If from any reason the hooks get injured or broken off, little pieces of wire have to be soldered on, which is not good. It would be much more satisfactory if the wires terminated in fixed contact blocks, and the fitting, wired complete and provided with spring contact plungers, were then independently attached. In the "Shikishima," combination

fittings, carrying electric lamps and candles, were wired in this way by the author with success, the removal of four fixing screws allowing the fitting to be bodily taken away without disturbing the main wiring.

SIGNAL LIGHTS.

Every ship, of course, carries the ordinary international navigation lights, port side red, starboard side green, and

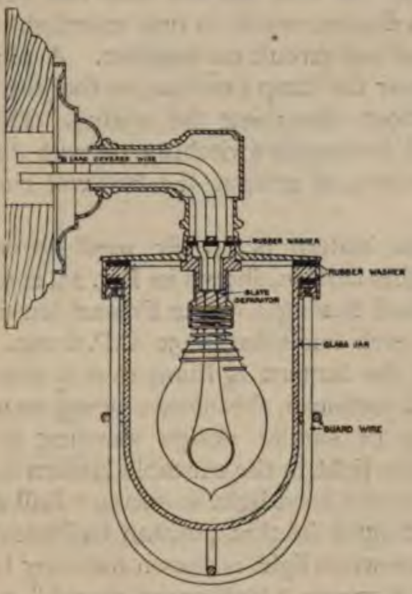


FIG. 13.—Admiralty Pattern Watertight Bracket.

mast-head white, which must be alight all the while the vessel is under way, together with white riding lights, which have to burn when the ship is at anchor. In British ships, so-called "position lanterns," two in number, are carried on the ensign staff when at anchor. In order to provide against failure of the navigating lights, the lanterns sometimes contain two lamps with an automatic switch for throwing the second into circuit if the first fails. This does not, however, make a good arrangement, because both lamps cannot be placed in the focus on the Fresnel lens, and if one is right the other one must be out of position.

Tell-tale alarms (of which there are several kinds) are used on some ships to give warning if one of the navigating lights fails. Fig. 14 shows the arrangement devised by the author for the "Fuji" and "Shikishima." An electric bell is provided with a relay wound to one-tenth of an ohm and carrying the full current of the 50 C.P. lamp employed, say 2½ amperes. This relay magnet holds a spring contact out of connection with the bell circuit while the lamp current is on. On the failure of the lamp current, the spring contact completes the bell circuit, and the bell rings continuously. A duplex switch in one watertight case switches both lamp and bell circuit on together. A plug connection is attached near the lamp position, so that the lamp can be removed without disturbing the wiring. The bell circuit can be tested by merely switching on with this plug connection out, when, of course, the bell will ring if all is in order.

The Ardois lantern is largely used abroad for speed signalling. This lantern, shown in Fig. 15, is really a double lantern, one half having a white Fresnel lens and the other a ruby lens, each enclosing a 50 C.P. lamp. As used by the Japanese, the lantern is hung over a sheave from the fore starboard yard-arm, this sheave being surmounted by a single lantern of similar design showing a white light. When the white light in the movable lantern is shown burning close up to the fixed light it means "Full speed ahead," while the red light in this position indicates "Full speed astern." If the white light is shown half-way between yard-arm and rail it means "Half-speed ahead," a red light in the same position indicating "Half-speed astern." When the movable light is shown quite low down, it means "Slow speed ahead," and the red light in the same position "Slow speed astern." The white lenses are slightly obscured because it is thus more easy to see the two separate lights when close together than if clear glasses are used. Two white lights and a central red one, in lanterns on the after-bridge rail, are used for the same purpose, and screened so that the light shows only astern.

Among minor signals may be mentioned that employed to indicate "Admiral aboard." On British ships, three lamps are hung respectively at the ends and centre of the after-bridge rail, and one from the military top; on Japanese

vessels three lamps are hung in triangular fashion from the after military top. The same three lanterns hung in various positions are used by the Japanese for other signals.

For general fleet signalling, flashing lamps carried at the truck of the foremast are in fairly general use. They are designed so that any communication can be effected by the use of the ordinary Morse code In one design of mast-head lantern due to Captain Scott, and made by Messrs. Armstrongs, the lamps, which burn continuously, are enclosed in a lantern surrounded by two

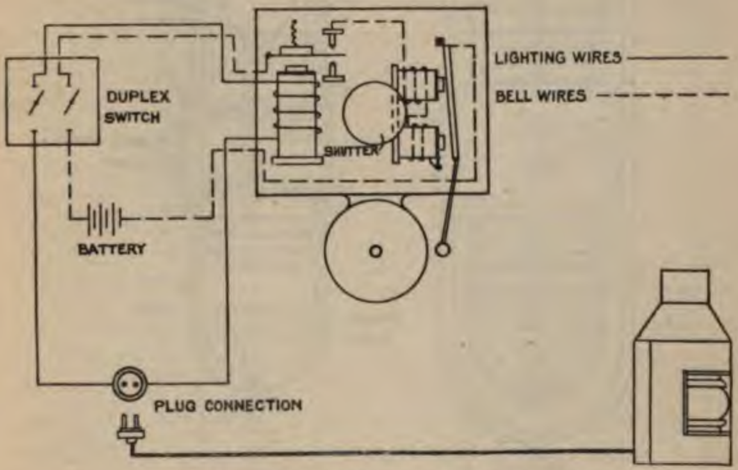


FIG. 14.—Navigation Lights Alarm, "Fuji" and "Shikishima."

louvre screens, one fixed and the other movable. The movable screen is attached to the armature of an electromagnet, through which currents are sent when the signalling key is depressed. The lantern may be arranged so that openings in the louvres coincide and the lights are visible when everything is at rest, the movement of the screen cutting off the light and thus representing the interval between the signals, or *vice versâ*. A modification of the Scott lantern as used by the Japanese is shown in Fig. 16. It consists essentially of two lanterns, one above the other, the lower one being enclosed in a ruby glass screen. There are independent signalling keys for the two lanterns, the contacts of which are shunted by a condenser and resistance

to kill the sparking. In the figure the screen is shown to a larger scale for clearness.

The British mast-head lantern is of different design,

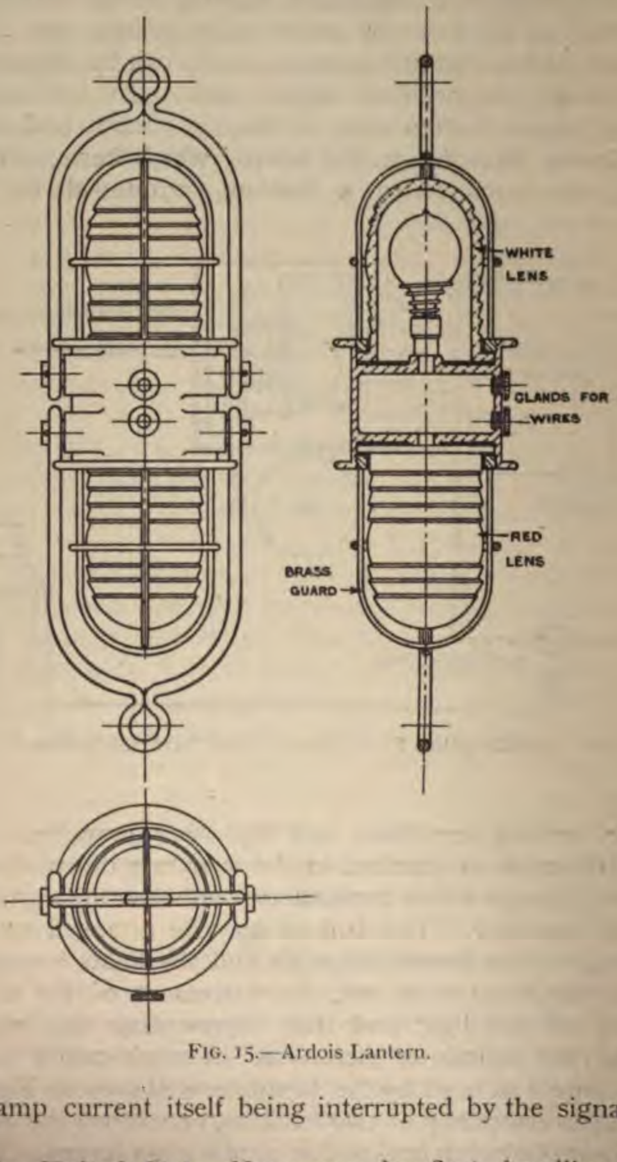


FIG. 15.—Ardois Lantern.

the lamp current itself being interrupted by the signalling key.

The United States Navy uses for fleet signalling four Ardois lanterns, the upper light in each being red and the

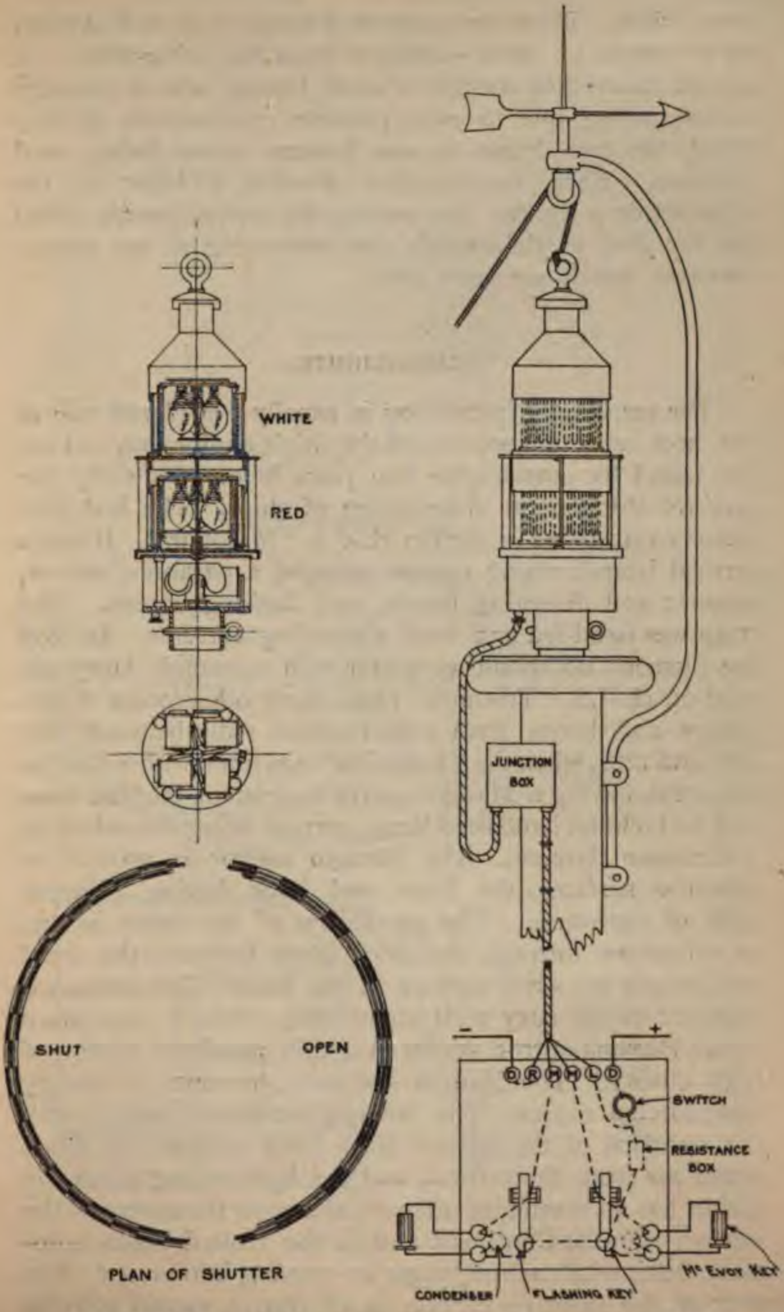


Fig. 16.—Double Mast-head Flashing Lantern, "Scott" System.

lower white. These are suspended about 10 or 12 feet apart on a couple of wire jackstays from the after-mast. A special controlling switch is used, having sets of contacts corresponding one to each possible combination of four lights, the two lights in one lantern never being used together. Each combination denotes a letter of the alphabet or a figure. By moving the switch-handle about the top dial of the switch and depressing at the proper contacts, words are spelt out.

SEARCHLIGHTS.

The searchlight installation is usually considered one of the most important sections of the ship's equipment, and use was found for searchlights five years before electricity was used for the general illumination of ships. The first projector was installed in 1876 in H.M.S. "Minotaur." It had a vertical lamp burning square carbons, a parabolic mirror, dioptric and diverging lenses, and flashing screen. The lamp was hand-fed and took alternating currents. In 1878 the Siemens holophote projector with automatic lamp was tried on H.M.S. "Triumph"; and many other forms of projectors and lamps were experimented with between that date and 1881, when the "Inflexible" was fitted with a Mangin projector, having a Mangin mirror instead of dioptric lens, and an inclined hand-feed lamp, current being furnished by a Gramme dynamo. The Mangin mirror is ground to spherical surfaces, the front and back having different radii of curvature. The parallelism of the beam is due to refraction through the thick glass between the front surface and the silver surface of the back. This remained standard in our navy until about 1893, when it gave place to the Parsons mirror, which is a thin parabolic mirror of high quality. The Mangin system is, however, in use by most foreign navies. The inclined hand-feed lamp is still the standard of the British Navy; the carbons are tilted about 20° from the vertical, and the light falling upon the mirror has its maximum intensity at or near the centre of the mirror. On the Continent and in the United States automatic horizontal carbon lamps are coming into favour. The crater of the positive carbon is, of course, turned towards the mirror, the arrangement in this case giving the maximum

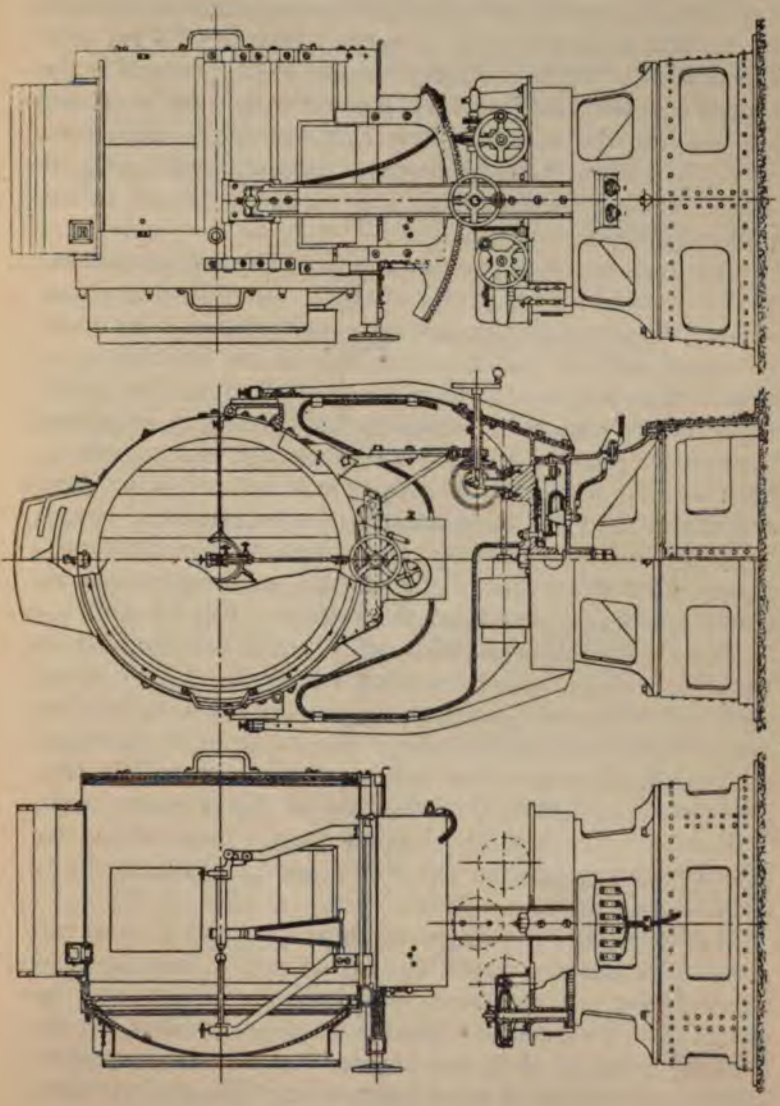


FIG. 17.—Schuckert Automatic Projector.

intensity of the light at the outer edges of the cylindrical beam. The British War Office has also adopted the horizontal carbon lamp for its standard projectors. The ascending current of air is apt to displace the arc, which is specially inconvenient with horizontal carbon lamps. To get over this difficulty, the Schuckert projector, Fig. 17, which is the standard in the Austrian Navy, is fitted with a soft iron ring surrounding the carbon. This ring becoming magnetised when the current flows produces a magnetic field along its axis in which the carbon lies, and so keeps the arc in the proper position.

It is now becoming common practice by foreign nations to operate searchlights from a distance. An observing officer can see the object illuminated very much better if he occupies some different position from that of the searchlight, so that he does not have to look along the beam. But as he must have a means of directing the light, it is becoming common to provide projectors with electric motors, one to train and one to elevate the projector barrel, including lamp and mirror, and also to fit projectors with automatic lamps. This operation is specially advantageous as regards projectors fitted at the tops of the military masts which can be conveniently operated from the bridges. Fig. 18 shows a Siemens electrically controlled projector of this kind. It is worked by a combination switch consisting of two motor starting switches mounted at right angles to one another and worked by a single handle. The operation of directing the searchlight is done by moving the switch-handle precisely as if one had hold of the back of the projector itself. The projector is instantly stopped upon a given object by bringing the handle to the "off" position, which short-circuits the motors.

As fitted on the bridges of ships, projectors have two positions, a working position right out, and a stowing position in board. At the stowing position they are secured by chains and turn-buckles to anchor-plates in the deck; in the working position they are secured by a small eccentric motion, worked by a hand-lever, which lifts the projector base slightly from its trolley wheels and jambs it on to the underside of a flange in the rail on which the projector runs.

Searchlights are used a good deal now for long-distance

signalling, and very great distances indeed have been covered. The common way is to make use of a round disc suspended on a spindle running through the projector barrel between the lamp and the mirror, and vibrating this disc by means of a small lever handle on the spindle. The arrangement is seen in Fig. 18. In some recent foreign projectors a flashing screen, resembling somewhat a Venetian blind with the laths vertical, has been fitted in front of the front glass; the laths are linked together, and their movement from the position in which the full light is shown to that in which all the light is cut off, is controlled by a small lever-handle mounted at the side.

Voice-Pipe and Bell Communication.

The problem of maintaining communication between the several compartments, cabins, and military positions in a warship is not less important than the problem of maintaining general illumination, but it is far less successfully solved. As regards the communications between officers in their cabins and their subordinates and sentries, a simple system of bell signals with annunciators or "shutters" is all that is required; but communications between the navigating officers on the bridge and the engine rooms, and between combatant officers in the conning tower and the gun and torpedo stations, for example, may often be of a much more complex and special character than can be easily given by a simple code of bell signals. Beyond a certain point, means of verbal or telegraphic communication becomes necessary. Such communications in our navy are effected by speaking through copper voice-pipes of 2-inch diameter, fitted with whistles or electric bells, pushes, and shutters, the latter serving merely to direct attention to the voice-pipe. These electric-bell communications are very extensive in a modern ship, the number of points from which verbal messages can be sent or received being about 100 in the battleships of our "Majestic" class and about 140 in the "Canopus" class. A greater elaboration, however, than in any other ships afloat was affected in the Japanese battleships "Fuji" and "Yashima," which were equipped with as *many as 256 electrically* connected speaking points, in addi*tion to 44 cabin* bell-push points.

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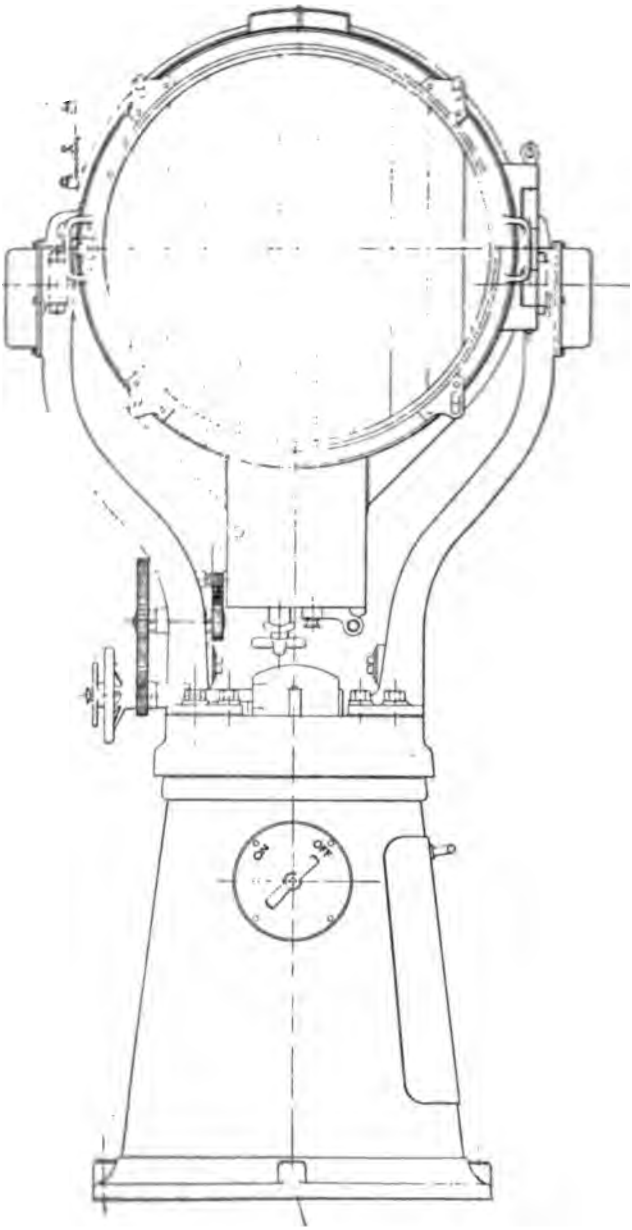


FIG. 18a.—Siemens Automatic Projector.

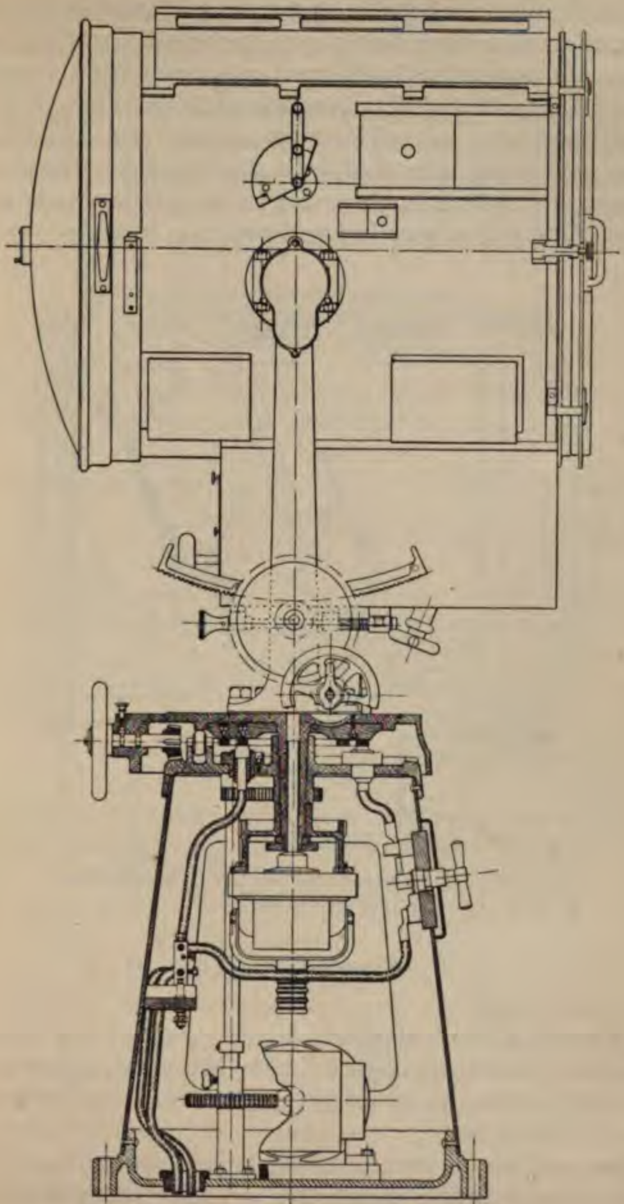


FIG. 18*b*.—Siemens Automatic Projector.

The connections between stations are effected by four-core cable, the conductors being 1/16, separately insulated with rubber, and covered with different coloured cotton coverings to facilitate making and tracing connections. The electrical connections of a pair of instruments are given in Fig. 19. When, as is usual, several pipes and instruments occur at the same station, all the branching and jointing is done in terminal boxes. One bell is usually fitted common to the group, and

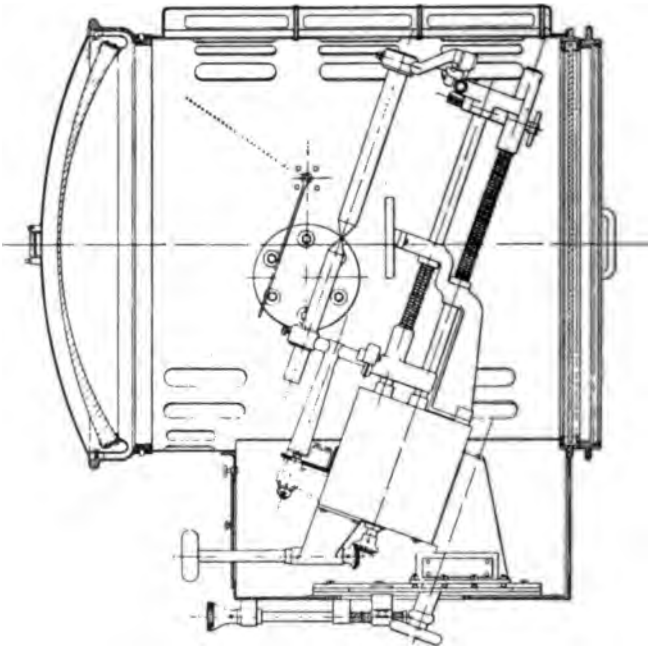


FIG. 18c.—Siemens Automatic Projector.

one six-cell battery supplies several groups, the connections being made through suitable battery terminal boxes. The whole system is watertight, and no jointing of wires is done outside boxes.

The problem of communication is, however, not solved by the present arrangements, the difficulty being that when the electric bells have done their duty, and the officers who wish to communicate are at the opposite ends of the voice-tube, there is often so much extraneous noise that it is impossible for them to hear one another. It has been usual

in recent years carefully to insulate the tubes from the main structure of the ship, so that they shall not pick up sounds by conduction, and the device has been employed of leading the speaking-tubes to about six exchange stations where messages are received and transmitted, so that the length of tube spoken through between point and point is reduced to the smallest limits. The transmission of messages at exchange stations, however, introduces delay and sometimes error.

TELEPHONES.

The failure of voice-tubes has given telephones their opportunity, the speaking qualities of the latter being

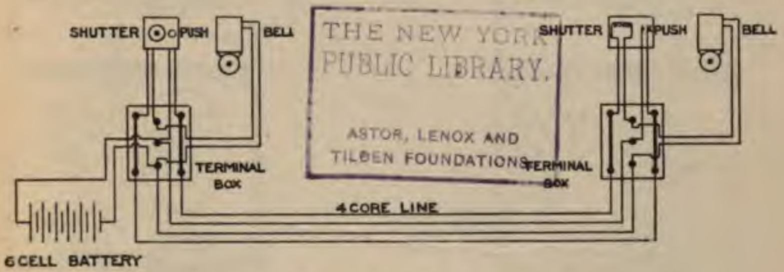


FIG. 19.—Voice-pipe Bell Instruments, diagram of connections.

practically independent of distance. Among the earliest to use telephones on warships were Russia and America. One of the best forms of naval telephone, and one that is now being largely used, not merely by the British, but by many other navies, is Alfred Graham's. It is a loud-speaking instrument, the transmitter taking the current of four or six large agglomerate Leclanché cells, and operating without an induction coil. The transmitter is of granular type, enclosed in a watertight case. It is turned half-round every time the telephone is used by the switch which puts the line connections from "ringing" to "speaking." In spite of the large power employed there is no hissing. The receiver is contained in the same case. A considerable number of British battleships and cruisers are fitted with voice-tubes and bells between the port-engine room and the bridges and conning towers, and with these telephones between the starboard engine-room and the bridges and conning towers, the

intention apparently being to gain extensive experience of the relative efficiency of voice-tubes and telephones under identical conditions. Telephone connections in a typical case are shown in Fig. 20. The most advanced instance of naval telephones yet fitted is to be found in H.M. new yacht "Victoria and Albert," which has a large telephone installa-

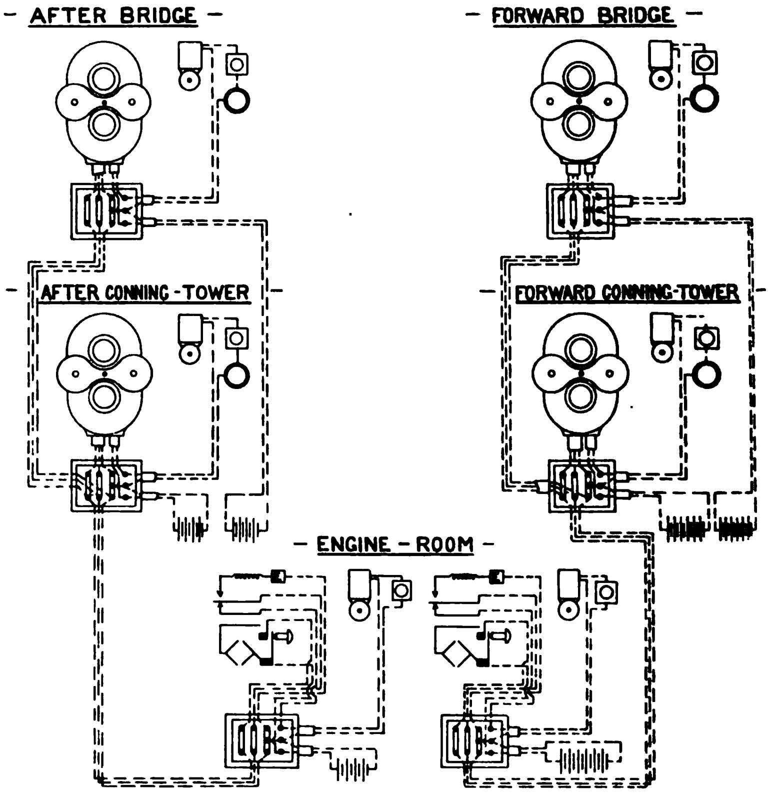


FIG. 20.—Graham's Loud-Speaking Telephone, connections.

tion. Trials are also being made of the applicability of these telephones to communications between casements.

It would appear, however, that during actual warfare, amid the noise and rattle of quick-firing guns, any instrument that depends upon the transmission of the human voice must fail. It is reported that in the battle of Santiago the Americans found their telephones useless. Unless a

large number of men are to be told off as messengers to carry orders, what seems to be wanted is a system of printing telegraphs, the instruments being of a not too sensitive character, so that they could work without giving false signals due to vibration and shock, the general design of the instrument being somewhat after the fashion of that used by the Exchange Telegraph Company, printing in ordinary Roman letters. Such an instrument would have a relatively

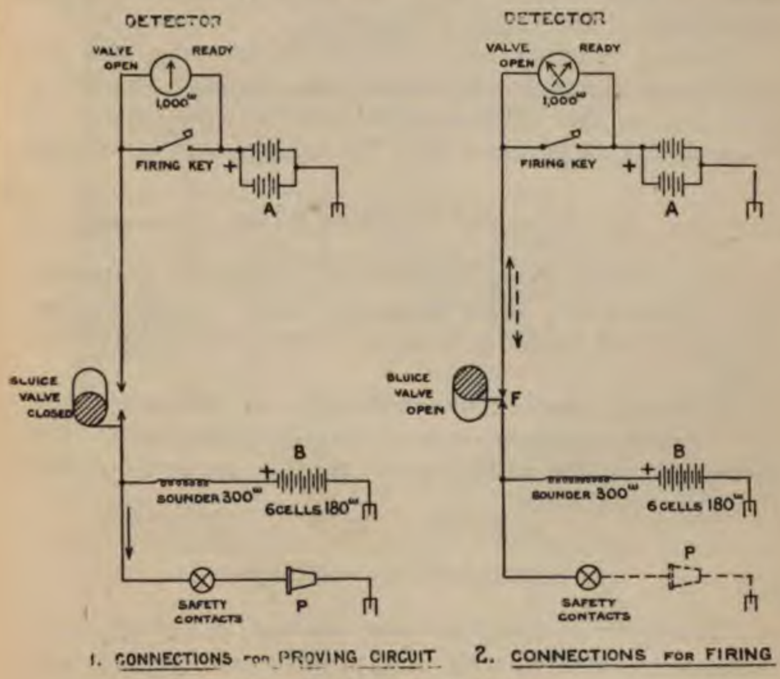


FIG. 21.—Torpedo-Firing Circuit.

slow speed of action, but its result would be more positive, inasmuch as the message could be read by a person without a telegraphic training, and if by chance a false letter were printed, it would not necessarily prevent the word from being recognised. Probably its speed—twelve to twenty words a minute—is as quick, all things considered, as the average voice-pipe communication now. Of course, messages making inquiries or giving instructions in accordance with understood requirements could be transmitted by abbreviated signals.

Before leaving the subject of communications, it may be mentioned that steps are being taken to introduce into the navy the "Sullivan" galvanometer for enabling ships at sea to speak with the land through ordinary submarine cables. There is some prospect also that warships will make general use of the Marconi telegraphic apparatus for fleet and ship-to-shore communications. This apparatus proved very useful in the 1889 manœuvres, and equipments have since been supplied to some of the battleships of the Channel Squadron.

Among internal bell communications may also be mentioned alarms connected with thermometers for calling attention to the attainment of certain temperatures in magazines, coal bunkers, etc. The arrangement is obvious.

Gun and Torpedo Work.

Electricity is an indispensable adjunct to the armament of a man-of-war, being invariably used for discharging torpedoes and for firing modern breech-loading guns of all sizes.

While all other circuits in the ship are twin-wired, gun and torpedo circuits are now universally single-wired. The following are the arrangements used in connection with Elswick equipments.

Torpedo-firing Circuits.

Two batteries, one (A) of low, and one (B) of high resistance, are connected with their positive poles towards one another as shown in Fig. 21. The firing key and detector are fitted in the conning tower, from which the discharge of the torpedo is controlled. The torpedo is placed in the tube, the sluice-valve at the outer aperture of the tube being closed. The valve being closed, the firing circuit is open. The circuit is then "proved" by inserting a primer in the firing breech, when current flows from battery B, causing the sounder in the torpedo room to start buzzing, thus indicating that all is right. The primer is then removed and the sluice-valve opened, thus making contact at F, and completing the circuit through E, B, F, A, E, the two batteries being in opposition. The detector needle in the conning

tower deflects to the left, indicating "valve open." The firing charge is inserted in the discharge chamber, the primer restored and the breech locked. Current from battery A through the high-resistance detector then flows in unison with that from battery B in the circuit E, A, F, P, E, reversing the deflection of the detector and indicating "ready." The officer in the conning tower at the proper

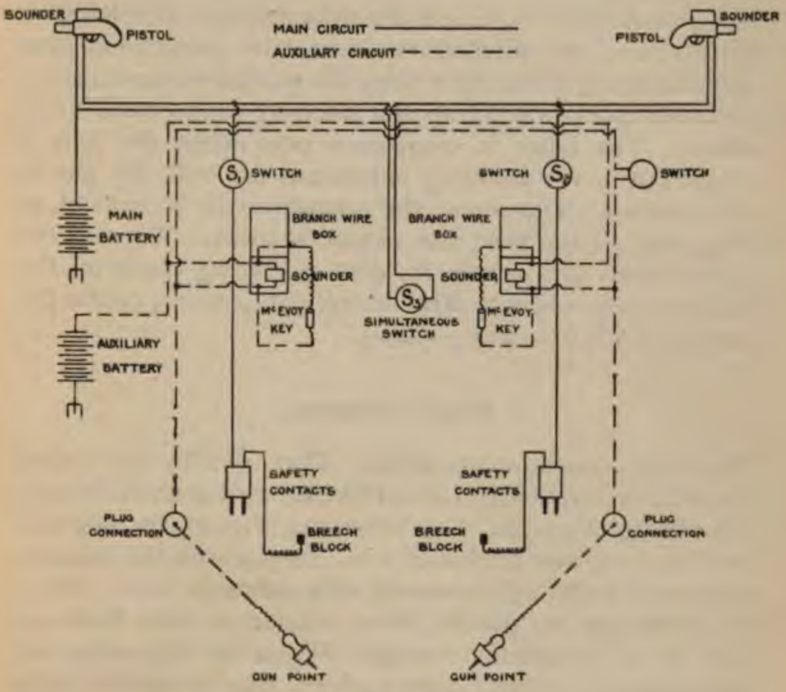


Fig. 22.—Gun-Firing Circuit.

moment depresses his firing key, the two batteries send their full volume of current through the firing circuit in parallel, the fuse is ignited and the torpedo discharged.

Gun-firing Circuits.

These a few years ago involved a formidable amount of wiring, as the circuits from all the barbette and casemate guns were looped into the conning tower, where the firing keys were

[redacted]

situated. The practice now is to fire all guns on short local circuits, the batteries, switches, keys, etc. being carried on the gun mountings. Fig. 22 shows the connections for a pair of Armstrong barbette guns. Following out the main (full line) circuit, it will be seen that if switches S_1, S_2 are closed and S_3 open, the left-hand pistol will fire the left gun and the right-hand pistol the right gun. If switch S_1 is open and S_2, S_3 closed, the left pistol fires the right gun; while if S_2 is open and S_1, S_3 closed, the right pistol fires the left gun. Finally, if all the switches are closed, both guns can be fired simultaneously from either side. An auxiliary circuit, shown in dotted lines, is fitted up as a stand-by to the main firing circuit. The latter is completed only when the gun is "right out"; the auxiliary circuit can fire with the gun in any position. The use of the sounders will be evident, as they buzz all the time the circuit is made. Whereas the firing pistols are usually fixed at the firing platform, the McEvoy keys, connected by flexible connections, enable the gunner to fire from any position.

RANGE FINDERS.

These are sometimes electrical. That used by the United States Navy, invented by Lieut. Fiske, is based upon the Wheatstone bridge principle. Two telescopes (Fig. 23) are mounted so as to move over graduated arcs. In gear with the trains of movement are cylinders wound with resistance wire. When the telescopes are parallel, these resistances form balanced arms of a Wheatstone bridge. When the telescopes are trained so as to bring a distant object into the field of both simultaneously, the electrical balance is upset and current flows in the galvanometer to an extent depending upon the arc of training, which is a trigonometrical function of the distance of the object from the centre of the base line connecting the two telescopes. The base line should be as long as possible, whence one instrument is usually mounted on the forward bridge and one aft, the galvanometer being in the conning tower where the firing keys are placed. It is necessary to know this base line with great accuracy, or errors creep into the range. Further, three observers are necessary, who must be connected with each other by telephone. The method is a delicate one, and the difficulty

of making the necessary adjustments, taken in conjunction with the difficulty of using the telephones during gun-firing, led, it is said, to the abandonment of the apparatus by the vessels engaged in the war with Spain, who found it easier to get the ranges by trial shots.

The range-finder used in the British Navy, and which has also been supplied to most foreign navies, is that of Barr and Stroud. It is designed for use by a single observer, but being a purely optical instrument does not call for detailed description here.[1]

The ranges having been found, the next step is to

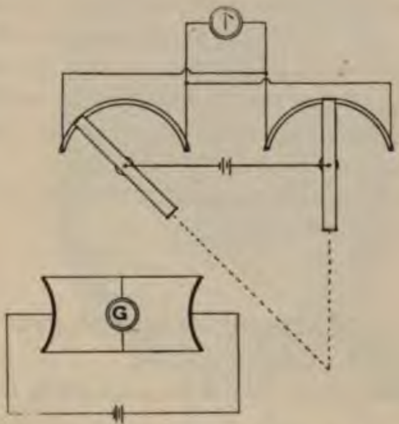


FIG. 23.—Diagram, "Fiske" Range Finder.

transmit them to the various gun-stations. For this purpose Drs. Barr and Stroud have invented a system of *Range and Order Telegraphs* for indicating simultaneously at any number of stations the range of a given object, together with information as to the guns which can be brought to bear upon it, and orders as to firing. Figs. 24 and 25 show the general appearance of a set of such instruments supplied to the Japanese, who are adopting them generally. The British Admiralty have them on trial. As fitted in the ship, a single transmitter near the range-finder position gives the range upon a receiver in the conning tower. Adjacent to this receiver are two double trans-

[1] It is described in the *Proc. Inst. Mech. Eng.*, January, 1896.

mitters for sending orders and ranges to the several casemates or to the barbettes, the receivers at which stations are grouped upon two main circuits, with bells which ring at every fresh signal received. The transmitters and receivers consist of clockwork mechanisms actuating, under electrical control, the movements of pointers over dial faces, on which figures representing ranges and symbols indicating orders are inscribed. The transmitter has an outside handle moving about the centre of the instrument. To transmit an order, this handle is moved until its index pointer is over the required symbol. On moving, it puts current, obtained by transformation from the lighting mains, into a small apparatus which starts an inside pointer following the outside index pointer. While this is moving, currents are being transmitted to the receivers at the distant stations and the whole of the pointers are set in motion. They all stop together over the symbol under the index pointer of the transmitter.

Being clockwork, the instruments have, of course, to be wound up periodically.

NAVIGATION INSTRUMENTS.

(1) *Engine-room Telegraphs and Helm Indicators.*

An electric system of engine-room reply telegraphs worked out by Messrs. Richards & Evershed was fitted in H.M.S. "Howe" and "Narcissus" in 1893, to H.M.S. "Royal Sovereign" in 1896, and since then in other British war vessels.

The indicating instruments have the appearance common to mechanical telegraphs, the dials being marked to show the usual direction orders "Stop," "Slow," "Half" and "Full," "Ahead" or "Astern." The revolution of the indicating hand is effected by the combined operation of two electro-magnets (see Fig. 26) placed at right angles to one another, and producing between them a cross magnetic field, within which lies a magnet with which the indicating needle is geared. The position of the needle depends solely on the relative strength of these two field components, and his depends on the ratio of the current in the two coil

FIG. 25.—A Group of Range and Order Telegraph Instruments.

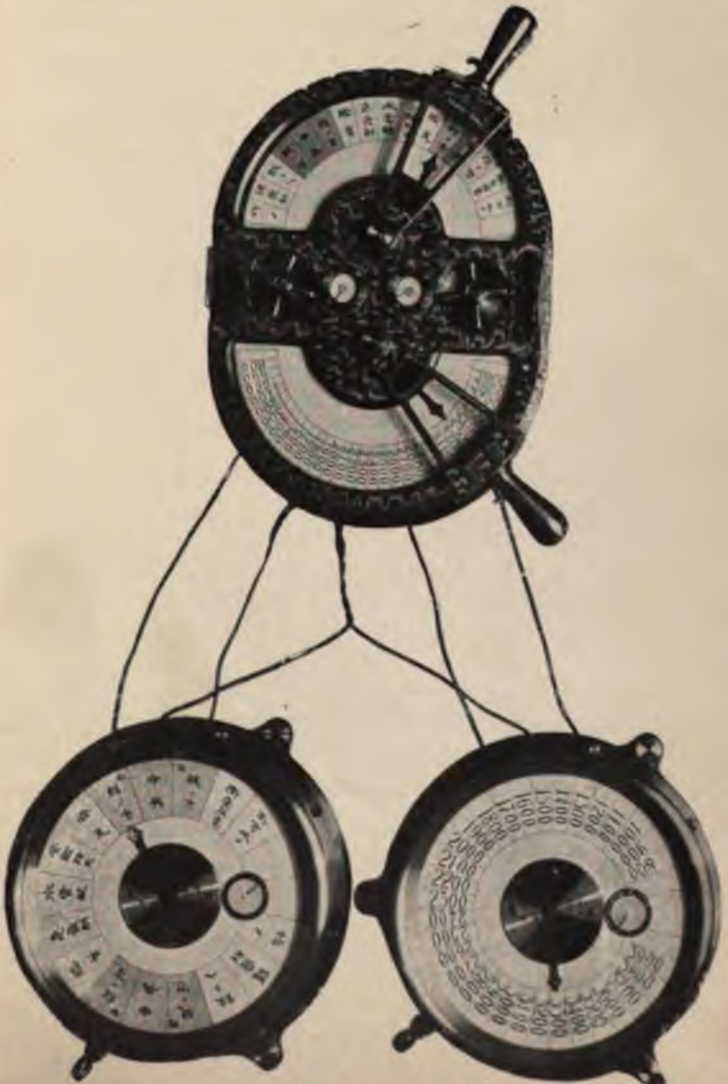


FIG. 24.—Barr & Stroud's Range and Order Telegraphs.

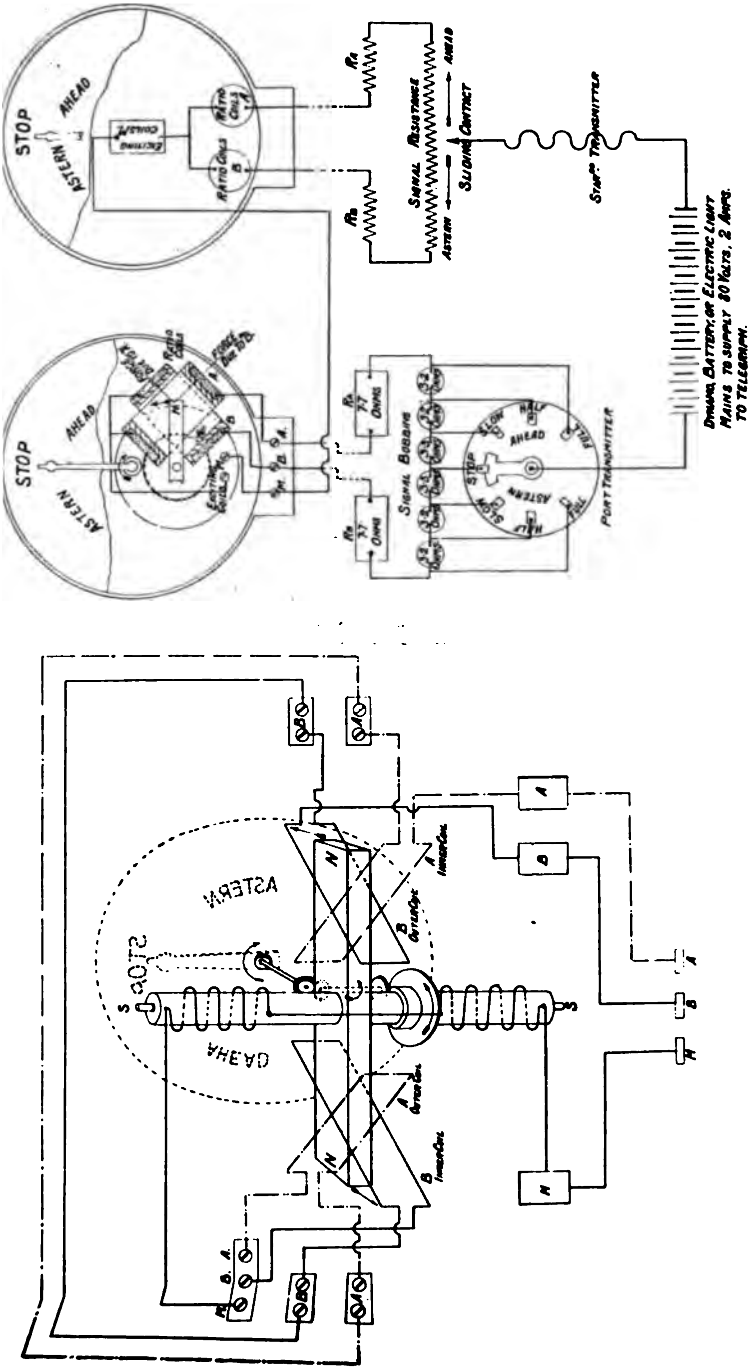


FIG. 26.—Richards and Evershed's Electric Engine-room Reply Telegraphs.

This ratio is controlled by the "transmitter," which consists of a multiple contact switch, through which the ordinary 80-volt electric light circuit is connected to a pair of ratio arms included in the same circuit as the coils of the indicator; the movement of the transmitter switches resistance out of one arm into the other, thus altering the relative value of the current strength in them, and controlling the movements of the indicator. An important detail is that the action does not depend on the absolute value of the currents in the indicator coils, but only upon their relative value, so that a constant voltage is unnecessary.

A similar indicating instrument, graduated in degrees, is used for showing, at the several navigating stations, the angle made by the rudder; the transmitter switch in this case being automatically worked from the rudder crosshead (Fig. 27). By means of switches these telegraphs can be arranged to signal from any of several working positions; bridges and conning towers to wit. Transmitters send orders from any of these stations to a common receiving instrument in the steerage flat.

(2) *Engine-room Indicators.*

A system for showing simultaneously in the bridge positions, conning towers, and other navigating stations, the revolutions of each set of engines, and for indicating in each engine-room the revolutions made not only by the set of engines in that room, but also by the set in the other room, is of great value. Such a system has been worked out by Signor P. Molinari, and has been adopted throughout the Italian Navy, and is also used on warships of other countries. The indicating instruments (Fig. 28) are direct reading in revolutions per minute. They are clockwork instruments, kept in synchronism by a standard clock. This standard clock has a commutator within it which sends current for 20 seconds into the coils of an electromagnet in the indicating instruments, then breaks it for 4 seconds, re-establishes it for another 20 seconds, and so on. While this current is on, the electro-magnet holds a detent which allows an escapement motion to drive the indicating …d over the dial. Correcting currents sent by a revolving …-maker driven by a friction wheel from the propelle…

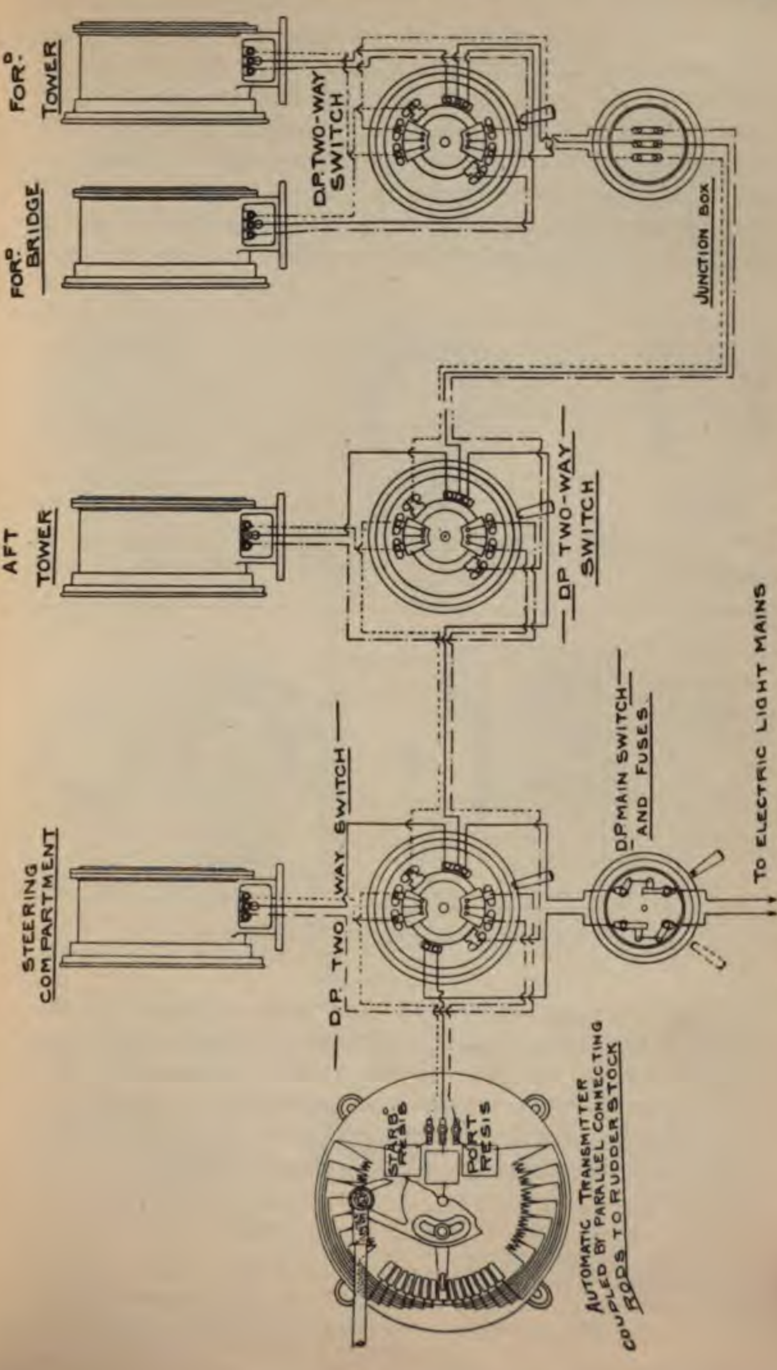


FIG. 27.—Richards and Evershed's Electric Tiller Transmitters.

shaft of the engine at the rate of three per revolution are received in separate electro-magnet coils in the instrument, and while the main current, controlled by the standard clock, is disturbed for the 4-second interval mentioned, the correcting currents drive the indicating needle forward or pull it backward according as the average rate of revolution of the engines has been less or greater than that shown at the moment on the dial of the instrument. A galvanometer

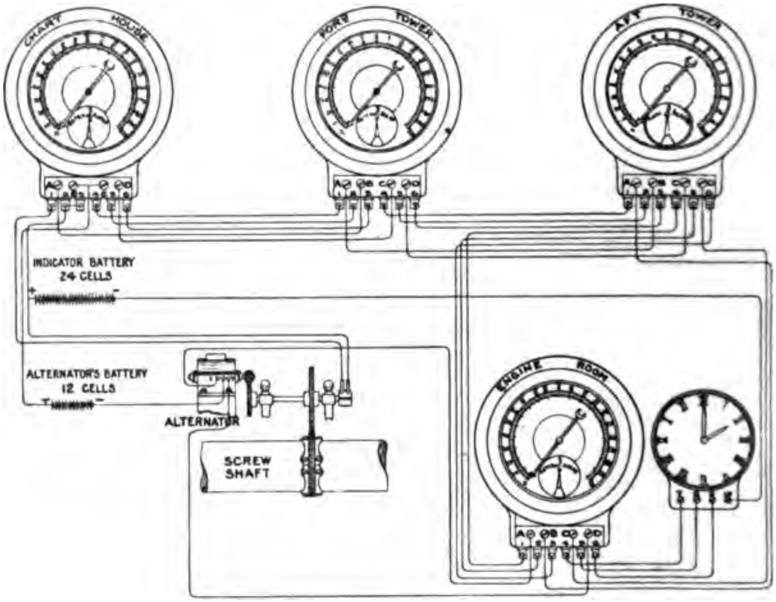


FIG. 28.—Molinari's Engine Revolution Indicators.

tell-tale for indicating "ahead" or "astern" is fixed in the bottom of the indicator case, and receives current from what is called by the inventor an "alternator," driven from the shaft in one direction or the other according as the ship is going ahead or astern. When no current passes at all the needle takes the mid position and indicates "stop."

PART II.

MACHINERY AND POWER DISTRIBUTION.

The machinery of a modern ship of war consists of—

(*a*) *Main Propelling Machinery*, consisting of high-speed steam engines and high-pressure boilers. From the figures given by Sir William White at the 1899 meeting of the British Association at Dover as to the output and efficiency of this class of machinery for a given weight, and from calculations made by Mr. Alexander Siemens as to the weight of accumulators required to perform the same work, there is no difficulty in concluding that electricity will have no place for many a long day in the propulsion of large ships.[1]

(*b*) *Auxiliary Machinery*. This general title covers a variety of machines whose functions fall into three principal classes.

> (1) Those which co-operate with the main engines and boilers in the propulsion of the ship; *e.g.*, boiler feed-pumps, air and circulating pumps for condensers, fans for producing pressure in the stokeholds or furnace-blowing engines for working at "forced draught," steering engines, capstans for raising anchors, etc.
>
> (2) Functions relating to the operation of the ship as a fighting machine; *e.g.*, engines for moving turrets and for elevating and loading guns, hoists for raising

[1] "With modern twin-screw engines and high steam pressure each ton weight produced from 6 to 7 horse-power."—Sir William White, loc. cit., *Engineering*, lxviii. 341.

"A 6,000-ton ship propelled by 8,000 I.H.P. will take about 150 hours to cross the ocean, equal to 1,200,000 horse-power hours. Fairly efficient accumulators give about 10 watt hours per 1 lb. of their weight, so that a horse-power hour can be obtained for 75 lbs. of accumulators. The ship in question would therefore have to load about 40,000 tons of accumulators for the trip across the Atlantic."—A. Siemens, loc. cit., *Journal Soc. Arts*, xlvii. 820.

In other words, for 150 hours steaming, 1 horse-power is produced from 5 tons of accumulators; hence, neglecting weight of electric motors and accessories, electric propulsion is inferior to steam propulsion on the score of weight in the ratio of at least 1 : 30.—AUTHOR.

[illegible] the experience [illegible] the methods [illegible] equipment four [illegible] that judged by [illegible] naval designers [illegible] backward than they [illegible]

[illegible] machinery works

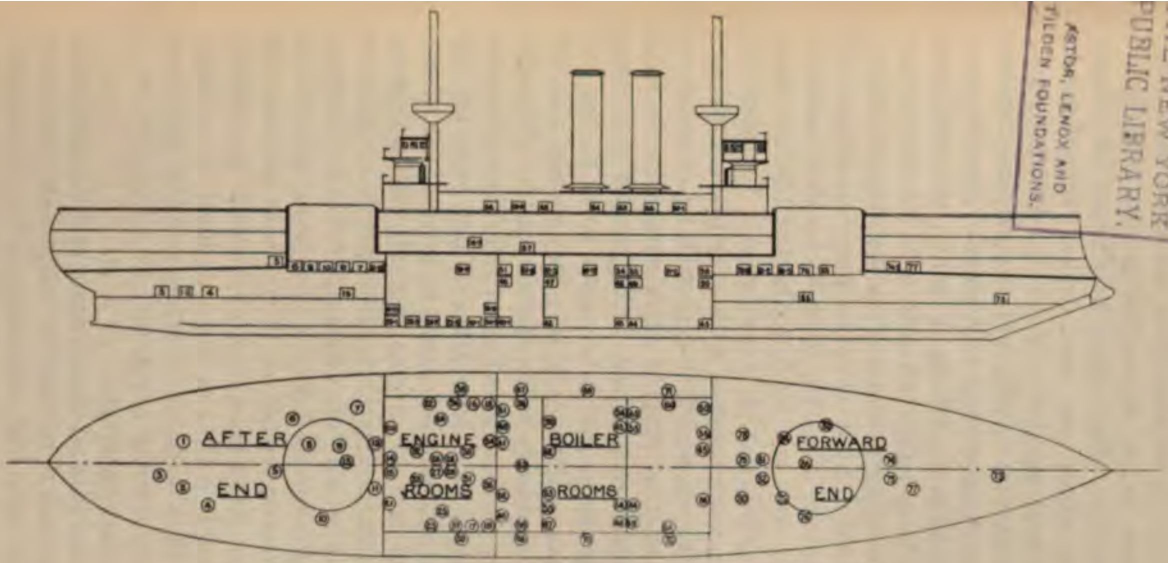


FIG. 29.—Location of Auxiliary Machinery on a Typical Battleship.

1–2.	Steering Engines ..	2 sets
3.	After Capstan.	
4–7.	Ventilating Fans ..	4 sets
8–9.	Air Compressors ..	2 sets
10.	Main Hydraulic Engine.	
11–12.	Turret Turning Engines	2 sets
13.	Turret Auxiliaries—Shot Hoists, Rammers, etc.	
14–15.	Steam Dynamos ..	2 sets
16–19.	Main Circulating Pumps	4 sets
20–21.	Auxiliary " "	2 sets
22–25.	Air (*i.e.* Hotwell) Pumps	4 sets
26–29.	Fire and Bilge Pumps	4 sets
30–31.	Starting Engines ..	2 sets
32–33.	Turning Engines ..	2 sets
34–35.	Distiller Pumps ..	2 sets
36–37.	Ventilating Fans ..	2 sets
38–39.	Ammunition Hoists ..	2 sets
40–45.	Boiler Feed Pumps ..	6 sets
46–50.	Furnace Air-Blowing Engines	5 sets
51–56.	Ventilating Fans ..	6 sets
57.	Steam Dynamo.	
58–59.	Boat Hoists	2 sets
60–61.	Coal "	2 sets
62–66.	Ash "	5 sets
67–72.	Ammunition Hoists ..	6 sets
73.	Capstan Engine.	
74–75.	Refrigerators	2 sets
76.	Workshop Engine	
77–80.	Ventilating Fans ..	4 sets
81–82.	Air Compressors ..	2 sets
83.	Main Hydraulic Engine.	
84–85.	Turret Turning Engines	2 sets
86.	Turret Auxiliaries—Shot Hoists, Rammers, etc.	

[illegible] have
[illegible] produced
[illegible] be met to-day.
[illegible] which motors ful-
filling some of the above conditions have been put on
the market. The cheap dock motor, suitable only for dry
[illegible] land with good foundations, and requiring

careful attention, has been installed and sent to sea. When, as is inevitable, such motors fail, the report sent in is less likely to be to the effect that "This particular motor is unsuitable" as that "Electricity is not adapted to this class of work."

The modern traction type of motor best meets, on the whole, the requirements laid down as necessary for ship work, and the conditions under which it actually works on land are as bad, if not worse; yet the accumulating experience of the world that such motors will endure the very roughest usage, makes it unnecessary to argue further that enclosed motors can be built, of moderate weight and cost in relation to output, that will leave nothing to be desired on the ground of reliability.

Reliability being the first consideration, the next in importance is simplicity in operation, combined with ease of inspection and repair. An electro-motor is a simpler machine to operate than a steam or hydraulic engine. It has fewer working parts requiring attention. Indeed, if only attention is given to supplying the bearings with oil and to cleaning the commutators periodically, there is nothing else for an attendant to do. Also a motor is cleaner in operation; it is not necessary to drain out a pipe full of water before it will start, and not only is the mess due to the absence of drainage water saved, but there is the advantage that the motor can be started instantly.

Cables for motors may, in like manner, be held to be a simpler means of transmission than steam or hydraulic pipes; they are more easily led about, weigh less, and take up less room than pipes capable of conveying an equivalent power, and they interfere less with the structure and disposition of space in the ship. It has been objected against them that faults in cables are not so easily found as in the case of steam-pipes, but if the cables are originally water-tight and are led about the ship from point-to-point junction or fuse boxes, it is not difficult to isolate the sections one at a time and locate the fault rapidly. If a fault exists, when it is found it can be repaired much more expeditiously than a leaky joint or other fault in pipes can be, especially steam-pipes, which have to be allowed a long time to get cool before they can be handled. Further, if it is not convenient to repair a cable fault immediately, a temporary length of

cable, not necessarily of the same size, can be run in and the faulty section disconnected; this cannot be done with pipe systems of distribution.

American writers point out two other disadvantages attending the use of steam-pipe systems of distribution—(*a*) that the steam-pipes heat the living spaces to an uncomfortable extent, (*b*) that pipes exposed to the effects of shot and shell are likely to be injured in action, and to lead to the demoralisation of the guns' crews. Neither of these considerations apply to modern British ships. Steam-pipes do not pass through living quarters. Pipes to the steering and capstan engines pass through certain storerooms below the protective deck, but these are so chosen that the heat is unobjectionable. As regards the pipes to the deck hoists, which are exposed, they are usually led up the stokehold fidleys amidships, and are provided with valves below by which they can be shut off from the steam main in time of action.

EFFICIENCY.

The mechanical efficiency of an electric motor is as a rule a few per cent. higher than that of a steam engine of corresponding power. The efficiency of the system as a whole involves the consideration of the generating and distributing arrangements, and here electricity has a marked advantage over either steam, compressed air, or hydraulics, the power taken being strictly proportional to load and the overhead efficiency from I.H.P. of generators to B.H.P. on motor shafts averaging about 65 per cent. at full load.

Efficiency, however, cannot be considered alone. The Naval Architect wants the relative advantages of competing systems expressed in terms of weight and space. In a given ship of war, the correct adjustment of weights and dimensions is correlated with the maximum offensive and defensive qualities involved in armour and armament, speed, and coal endurance. Hence, unscientific as it may appear in itself, an electric power distribution system of high mechanical efficiency may be a positive disadvantage to a warship if the weights involved conduce to an un-

favourable design in the offensive and defensive qualities of the ship. Whether the change from steam to electric driving of auxiliaries involves the sacrifice of greater weight than is compensated for by the advantages gained is precisely the question on which authorities differ—the differences being chiefly due to the use of general terms for the sake of the argument instead of precise calculation.

The main sources of loss in operating steam-driven auxiliaries are three: (*a*) The use of too great a range of temperature and pressure in the cylinders. (*b*) Leakages past pistons and valves due to wear. (*c*) Steam-pipe condensation.

(*a*) As illustrating the uneconomical use of steam under the first condition, consider the case of winches and capstans. These must exert a powerful effort in starting, and hence must have very little lead and lap to their valves. If therefore steam at, or near, boiler pressure, say 250 lbs., be taken with cut-off at, say, $\frac{3}{4}$ stroke, and discharged into the condenser at the end of the stroke, it is obvious that the steam consumption per I.H.P. must be very high. Steam engineers are well aware of this, and the increase in boiler pressures of the last few years has led to the introduction of several methods of utilising steam in auxiliary machinery to better advantage. One obvious but not-too-commonly-employed method is the use of reducing valves in the steam supply pipes of auxiliary engines.

The favourite practice at present in the American Navy is to turn the exhaust from the auxiliaries into a feed-water heater, in which the latent heat is abstracted and the feed raised from about 80° or 85° F. to approximately boiling point; and when the power being developed in the main engines is too low for the feed to condense all the auxiliary exhaust steam, the surplus has been turned into a low-pressure evaporator. Notwithstanding the increase of back pressure on the auxiliaries by this arrangement, a saving of about 9 per cent. of coal used for auxiliaries is said to have resulted. In our navy, auxiliary feed heaters are being introduced for the same purpose.

Other devices for economising steam are: the employment of compounding devices for using the steam in stages, as, for example, operating some auxiliaries by the exhaust from others, supplying auxiliaries at full pressure and

[illegible] The [illegible] engines [illegible] at [illegible] cylinders were [illegible] and were large for [illegible] boiler pressure [illegible]. The results as [illegible]

[illegible] enough here, but even the [illegible] results leave much to be desired. How much [illegible] to similar causes in the case of the other [illegible] investigated, but the results were in all [illegible]. There is no corresponding loss due to the [illegible] in the case of electro-motors.

[illegible] Condensation in the steam-pipes is probably the most [illegible] of all the sources of loss. If we allowed that in the [illegible] the average steam consumption in pounds of [illegible] per I.H.P. of all the auxiliaries were brought down to the level of that of the dynamo engine—the most

[illegible] 1898.

[redacted]

Set.	Load I.H.P.	Steam lbs. per I.H.P. per hour.	Remarks.
No. 1	21·873	123·27	Pistons water-packed and bad fit to cylinders, cylinder bores rough and pitted.
”	19·598 33·601	88·64 68·25	New pistons with two cubic inch packing rings in each, in use about ten days.
”	29·184	69·33	New piston with packing rings in cylinders.
No. 2	19·012 30·354	108·71 84·03	Water-packed pistons, cylinder bores rough.
”	16·791 26·553	102·73 84·74	Do. do.
”	22·923 35·237	65·12 56·45	New pistons with packing rings, in use about nine days.
No. 3	17·324 26·234	97·75 79·48	Water-packed pistons; fit cylinders closely. Cylinders in good condition.
”	18·241 27·815	81·62 72·14	New pistons with packing rings, in use about four days.
”	20·40	97·92	Water-packed pistons.

efficient auxiliary in the ship—the margin of loss from condensation to be got rid of by the extended use of electromotors would go a long way to furnish the required set-off in coal-saving to balance the necessary increase in weight of the electric system. For it is to be remembered that this loss occurs not merely when the auxiliaries are exerting power, but goes on the whole time the ship carries steam, whether the engines are working or not. To illustrate this point, an instance may be mentioned that has recently come under the author's observation. The new first-class battleship "Shikishima" carries 25 Belleville boilers, capable under full steam of developing over 15,000 I.H.P. in the main engines, *besides* working the auxiliaries necessary for *steaming at full power*, driving dynamos, etc. Thus each

boiler at full power is equal to the supply of steam for over 600 I.H.P. When at anchor, one boiler under easy steam—*i.e.*, evaporating from 9 to 10 lbs. of water from and at 212° F. per pound of coal—was just able to work one 48 k.w. steam dynamo at about ½ power, together with one feed-pump and the air and circulating pumps connected with the auxiliary condenser into which the dynamo engine exhausted, besides working a fire- and bilge-pump occasionally. If a capstan engine or boat hoist had to be worked in addition, a second boiler was necessary. The dynamo was about 160 feet of pipe length away from the boiler, the total range of steam pipe connected being 500 to 600 feet. Performing the first-mentioned service with only one boiler alight, the coal burnt varied from 3½ tons to 5 tons per day of 18 hours for about 65 I.H.P., or about 7 lbs. per I.H.P. hour at the best to 10 lbs. at the worst, the average being over 8 lbs.; which shows that more than half the fuel must have been expended in keeping the pipes warm. All pipes were well covered and below decks, and all machinery new and in first-class condition.

Sir John Durston has published particulars of the coal consumption of certain auxiliaries of H.M.S. "Diadem," obtained when the ship was at rest in the basin, which bear on the same point.[1] He discovered that to run one main feed-pump, one blowing engine, one auxiliary circulator, one electric-light engine, and two distiller pumps consumed coal at the rate of 6·1 tons per day when two extreme forward boilers were employed, or 3·88 tons when two extreme after boilers were employed; the same machines with the addition of two evaporators, working compound, consumed 8·8 tons per day when supplied from the forward boilers, and 7·09 tons when supplied from the after boilers; *i.e.*, the elimination of the lengths of steam-piping between the forward and after boilers alone resulted in a saving of from 20 to 30 per cent. of the total coal used for the machines in question.

The same proportion of waste may be concluded to exist under sea-going conditions; for although more machinery would be at work, and therefore the steam would in some measure be used to better advantage, yet, on the other hand,

[1] *Transactions of the* Institution of Naval Architects, 1889.

the long lengths of pipes fore and aft of the ship would be connected to the steam mains, as well as branches going into colder regions above the protective deck. Hence it is clear that with short direct connections to steam dynamos, and electric distribution to all the other auxiliaries for which electric driving is suitable, a considerable saving of coal —probably at least 5 tons per day—would be effected under this head.

The total coal consumption for auxiliary purposes may be thus computed: Steaming at "economical" speed—about 12 knots—involving, say, one-fifth power, it is known that the coal consumption of a good modern first-class battleship or cruiser with Belleville boilers fitted with economisers is about 2 lbs. of coal per I.H.P. hour, which for 3,000 H.P. represents about 65 tons per day of twenty-four hours, of which the minimum number of auxiliaries employed under these conditions (*i.e.*, steering engine, pumps, distiller, and one dynamo) consume on an average about 25 per cent. = 16 tons. Supposing the engine-room pumps continue to be steam driven, the principal auxiliaries used when the ship is cruising under ordinary sea-going conditions will be, besides those mentioned, ventilation fans, ash-hoist engines, and refrigerating machinery, together with air compressors and turret machinery for drill purposes. These machines work intermittently, and hence average coal consumptions are to some extent a matter of speculation; but it will probably be below the actual consumption of many ships to take the average total coal consumption of all the auxiliaries employed in an ordinary commission at 20 tons a day,[1] or, neglecting the dynamo, 15 tons.

Turning to the broad question of the mechanical efficiency of electrically driven auxiliaries, notice must be taken of a couple of recent papers by Lieutenant Robinson, U.S.N.[2]

For purposes of comparison, Lieutenant Robinson takes the average steam consumption of the best steam auxiliaries now produced at just below 70 lbs. per I.H.P. hour. He

[1] The "Powerful" is said to have burnt on her voyage to China last year 40 tons a day for auxiliaries. The "Diadem" cruisers and the "Canopus" battleships are, however, much more economical.

[2] "*Auxiliary Machinery for Warships*," *Engineering Magazine*, October *and November, 1899.*

puts the best steam consumption of an electrical generator at 26 lbs. per I.H.P. hour, the exhaust being taken into a feed heater. He takes the efficiency of the engine at 93 per cent., dynamo 86 per cent., line 95 per cent., and motor 78 per cent., = overall efficiency 59 per cent.; and on this basis shows that the steam consumption per B.H.P. on the motor shaft is 44 lbs. per hour, representing a reduction of 35 per cent. of the steam used by the best steam-driven auxiliaries. He then goes on to argue that if electric motors are used to drive the auxiliaries, it will be necessary, in order to get the requisite torque at the highest speeds, to instal motors of 1·5 times the rated horse-power that would be required if steam auxiliaries were used; and hence, that as against a total of 1,500 I.H.P. of steam auxiliaries weighing (at 100 lbs. to the I.H.P.) 70 tons, a total motor capacity is required of 2,250 H.P., weighing on the same basis 105 tons.

The author ventures to join issue with this conclusion, which appears to be incorrect in several particulars:—

(i.) The I.H.P. of steam-driven auxiliaries is compared with the B.H.P. of motor driven auxiliaries, which is unfair. It would probably be liberal to allow an average mechanical efficiency for steam engines of the class used for auxiliary machinery of 70 per cent., so that if they consume 70 lbs. steam per I.H.P. this represents 100 lbs. per B.H.P. Hence the saving of coal due to electric driving is 56 per cent. instead of 35 per cent. (ii.) The only auxiliaries requiring maximum torque at highest speeds are pumps and fans, and it does not at all matter whether the torque exerted by motors on such machinery is equal to that exerted by steam engines, or not, provided the useful work done per minute is the same; on the contrary, services of this kind are excellently adapted to the capabilities of motors of comparatively small torque but high speed, the high speed allowing of a smaller and more compact machine than the slower running engine. (iii.) Winches, capstans, turret and steering engines, and in fact all in which inertia effects come in, require maximum torque *at starting*. Here the electric motor is distinctly on its own ground, for it is quite easy to build and control motors in such a way as to obtain from them a starting torque equal to two or three times that corresponding to their rated full power, which is

not the case with steam engines; besides which the motor has the further advantage of exerting a continuous rotary effort in lieu of the fluctuating turning moment of the reciprocating engine. (iv.) The argument as to the higher power rating of the motor drive appears to be drawn from the analogy of electrically-driven as compared with steam-driven machine shops, which is inapplicable to the case under discussion.

The conclusion appears to follow from the foregoing arguments that any appreciable increase in the horse-power rating of electric- as against steam-driven auxiliaries is unnecessary, and that if the whole of the auxiliaries of a 15,000 H.P. ship were electrically driven a saving of about 5 tons of coal used in generating the auxiliary steam would result from the suppression of pipe condensation, and (on the rather low basis of 59 per cent. overhead efficiency) a further saving of 56 per cent. of the balance of 10 tons = $5\frac{1}{2}$ tons, due to superior mechanical efficiency—a total of $10\frac{1}{2}$ out of the 20 tons of coal per day used by a good steam auxiliary equipment.

The total bunker capacity of a ship of the power mentioned would be about 2,000 tons, representing the ability to keep the sea for about 25 days at economical speed. The saving in coal consumption in these 25 days represents 262 tons on the basis shown—an amount sufficient to more than counterbalance the necessary additional weight of generators and motors carried.

The questions next arising are: to what purposes is it practicable, having regard to all considerations, to adapt electric driving, what would be the changes in weight, space, etc., involved, and what should be the arrangement of the installation for supplying the power?

There is a broad difference at once to be recognised between machines directly co-operating with the main propelling machinery and those performing other duties. On the whole, present engineering opinion is, from considerations of reliability, decidedly in favour of continued steam-driving for boiler feed-pumps, circulating and hot well pumps, fire and bilge and distiller pumps. It happens that these pumps are the worst steam-eaters in the ship; in the "*Minneapolis*," for example, the consumption ranged from

75·74 lbs. in a circulating pump doing 4·1 I.H.P., one cylinder alone taking steam, to 318·68 lbs. for a small pump developing ·78 H.P. which was used for flushing purposes, the average for the twelve pump tests included in Mr. White's tables being 161·61 lbs. per I.H.P. hour. Experience with electric auxiliaries in other situations may eventually lead to the use of electricity for these services; but this contingency may be left out of account for the present.

Starting and turning engines may be regarded as parts of the main engines themselves, and of course will be driven by the same power.

The only auxiliary services within the engine and boiler rooms for which the use of electricity may be considered at present are ventilation and furnace blowing.

Fans for Engine and Boiler Room Ventilation.

In the "Canopus" class of battleships each engine-room is ventilated by a 7 ft. 6 in. fan driven by a direct-acting steam engine, while the boiler-rooms are supplied with air from four 8-feet fans at 240 revolutions, and two 6-feet fans at 320 revolutions per minute. These represent in the aggregate about 150 I.H.P., with a weight of between three and four tons. The "Duncans" will carry two engine-room fans, each 6 ft. 6 in. in diameter, with two 8 ft. 3 in. and eight 6 ft. 6 in. fans in boiler-rooms, the speed being about 300 revolutions. Fan-driving, being a purely rotary movement, is a duty which electric motors have shown themselves excellently able to perform; they can run at at least twice the speed of reciprocating engines for the same power without noise or vibration, and can give the required deliveries with smaller fans, with higher efficiencies in both motors and fans, and therefore with less total power. It would probably be reasonable to take the total power of motors to perform the engine- and boiler-room ventilation of the most powerful ships at about 80 B.H.P. on the fan shaft, say 100 E.H.P. input, which could be provided in enclosed type motors built for continuous work at 750 revolutions per minute for about three tons, or, allowing for the weight of the fans, an increase of not more than one ton on the above total weight.

Furnace Air-Blowing Engines.

These are high-pressure air-pumps adapted for delivering air at 15 to 30 lbs. pressure above the fires and into the combustion chambers of the boilers. A set of five such engines in the "Shikishima" weigh 5 tons 2 cwt., and develop an aggregate of 220 I.H.P. Pumping services of this kind are very efficiently performed electrically, but the substitution of geared motors for engines would result in this case in an increase of the total weight probably to the extent of about 3 tons for 200 E.H.P. Furnace air-engines are generally placed in the boiler-rooms, but if electrical they could more conveniently be placed outside or above the boiler-rooms, air-pipes only being led into the firing compartments.

Considering next the auxiliary machinery outside the engine- and boiler-rooms we find these include steering engines, capstan engines, boat, coal and ash hoists, ventilating fans, air compressors, refrigerators, workshop engine, turret-working machinery, and ammunition hoists.

Steering Engines.

It is convenient to consider these machines in this section, as they are usually placed in the after steerage flat adjacent to the tiller compartment. In some of the latest British ships they are placed in the engine-rooms and connected by long lines of shafting to the tiller mechanism. This arrangement saves carrying steam-pipes aft, but seems to have nothing else to recommend it.

Next to the main engines these are the most important in the ship, and before every question of weight or efficiency the most reliable machine must be used here. Electric steering engines have, the author understands, been made, and there seems no reason, so far as the motors are concerned, why equally positive results should not be obtained with these and with steam engines. The controlling of their motion is the principal difficulty. The motors would be everlastingly starting, stopping, reversing, and *altering speed*; *or*, if the motors ran continuously, then *such movements* would be always being made by the gears

and clutches. And whereas the steering engine is deep down in the ship, the control has to be operated from distant stations, of which there are usually five, interconnected, the forward bridge and conning tower being the most important and the most generally used. Simple rheostatic control from a distance is not good enough; to secure the necessary sensitiveness, a large number of switch contacts and connections would be necessary; and an extensive system of cables interconnecting all the steering stations is inadmissible. A maker of steering engines once told the author he had invented an electric steering engine which he was sure met every requirement, but it required seventy-nine wires! The reply was, of course, that seventy-nine wires would kill any such project. Recourse must be had either to a pilot motor, worked by a small switch and two or three wires, operating in its turn the controller of the steering motor proper (indeed, it would probably be possible to employ the hydraulic telemotor, now so largely used, for working electric controlling switches alongside the steering motors, in similar fashion to that in which it reverses the valves of the steam steering engine), or to the interaction of two machines as in the Ward Leonard system of controlling turrets. If the difficulty of control be satisfactorily overcome, the gain in efficiency of electric steering mechanism ought to be very substantial, owing to its long periods of work. From its irregularity of working it is impossible to define the average H.P. of a steering engine. The motor to replace it must be a substantial affair, heavily geared, the torque required on the rudder-post of a big battleship being as much as 500 ton-feet. To move the rudder from hard-a-port to hard-a-starboard in 30 seconds, which is the usual requirement, a steering engine will make about 300 revolutions, and working at this maximum rate the I.H.P. will lie between 300 and 400, and the useful work done on the rudder-post will be at the rate of about 75 H.P. net, an overall efficiency of 20 to 25 per cent. Each steering engine with its gear weighs $5\frac{1}{2}$ to 6 tons; two sets are carried. If each steering engine were replaced by one motor capable of exerting the same starting torque, the full load rating of each motor on continuous work might be taken at 150 H.P., though the starting current allowed would correspond to twice this power. With electric driving, an

improvement in efficiency might be expected. The extra weight involved, using open-type machines, would be about two tons per set.

Capstans.

The principal capstan is, of course, the forward one, which has to operate the heaviest anchors. Besides other stipulations, its engines (usually duplex) are required by our Admiralty to lift a weight of 35 tons at the rate of 25 feet per minute = 60 actual H.P. The maximum I.H.P. may be taken at 200, and the weight of the complete capstan with engines and gears is about 47 tons. If electric motors were substituted for the steam engines with the same gears this weight would be increased by about two tons. But with better designed worm gears the work could be done electrically on the same total weight. The after capstan performs similar but lighter work, lifting 15 tons at 25 feet per minute = 25 actual H.P., say 75 I.H.P.

In our latest ships, while the forward capstan is still steam-operated, the after capstan is specified to be driven by two reversible watertight motors, performing the above specified work at speeds not exceeding 750 revolutions per minute, and so designed that the rise in temperature after one hour's run at full load does not exceed 80° F. This change involves an increase of total weight in capstan, motors, and gear of from one to two tons.

In lieu of two motors, the Admiralty have accepted for the "Duncans" and other ships an electric capstan driven by one 50 H.P. motor at 350 revolutions per minute, the weight of the complete capstan motor and gear being approximately the same as that of the steam after capstan of H.M.S. "Albion."

Fig. 30 shows the general arrangement of the electric capstan of H.M.S. "Irresistible" by Messrs. Clarke, Chapman & Co.

It will require a somewhat protracted experience to determine whether, on the whole, the use of electric motors for capstans proves advantageous. To be quite safe, motors should be used with a large margin of power, notwithstanding the increase of weight involved, for the stresses involved in such work are apt to rise with great

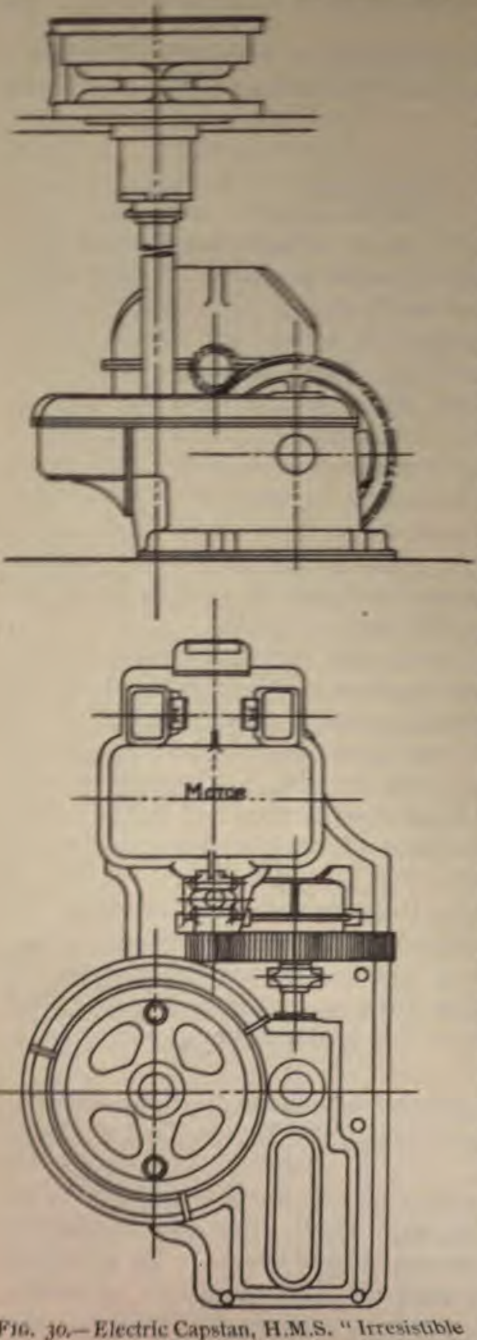


FIG. 30.—Electric Capstan, H.M.S. "Irresistible (Clarke, Chapman & Co.).

suddenness to many times their average value, and capstan chains have a habit of jamming in the stops. If steam driven, the engine will pull up, and is able to stand under the load; a motor cannot do this, yet it can neither be allowed to burn up nor to relinquish its work by cutting itself permanently out of circuit. Special devices are necessary to meet such a condition. Mr. Siemens dealt somewhat fully with this matter at Dover, so it is unnecessary to dwell further upon it here.

Neither in this case nor in that of the steering engines do there appear to be difficulties incapable of satisfactory solution electrically, and in these cases the longest steam-pipes in the ship are concerned.

BOAT-HOISTING ENGINES.

A British battleship carries two sets, one on either side,

of such power that each set can lift by means of tackle a boat weighing 18 tons at not less than 20 feet per minute. This is a favourable case for electric driving, and in the latest British ships electric motors are specified for the work. The actual net H.P. for the lift is approximately 24, and as the motors have to drive through a worm gear and a wire-rope tackle, the maximum input may be taken at about 50 E.H.P. The motors are specified to run at not more than 750 revolutions per minute, to be watertight, and to be fitted with reversing switches and automatic brakes. The rating of the motors is determined by the temperature limit of 80° F. rise after one hour's run at full load; which

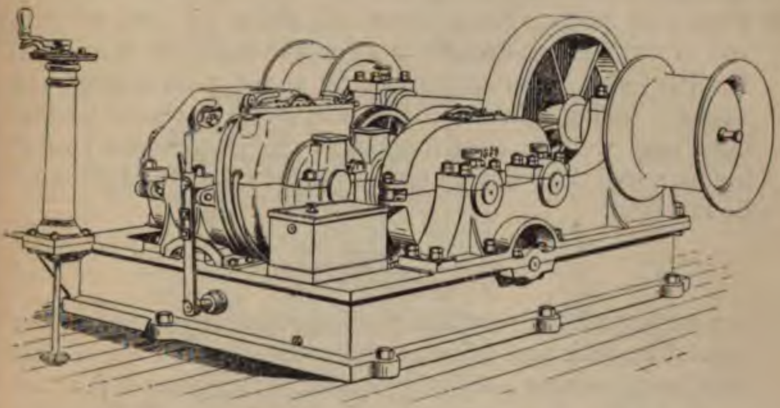


FIG. 31.—Electric Deck-winch, U.S.S. "Kearsarge" and "Kentucky" (General Electric Co., U.S.A.).

enables the weight of the total equipment to be about the same as that of the steam hoist.

An electric compound deck-winch, as fitted in the U.S. battleships "Kearsarge" and "Kentucky," is illustrated in Fig. 31.

COAL HOISTS.

These machines (of which two sets are carried) are of the same class as the boat hoists, but work at a quicker rate. The latest British specifications define their work to be the lifting of 1 ton at 250 feet per minute, but on test they have to lift *1½ tons at this* rate. On the test load they have *to exert 25 actual H.P.*, and though the efficiency may be a

little higher in this case than in that of the boat hoists, the total input will be 40 to 50 E.H.P. The motors therefore may well be of the same size; they are governed by the same specification as to temperature limit, control, etc. The weight of the motors and gears will probably be a few hundredweights more than that of corresponding steam hoists.

Ash Hoists.

One of these is usually fitted to each boiler-room; the "Albion" carries five. Their work is not definitely specified, but may be described as lifting with wire-rope tackle a bucket of ash, weighing when full about $1\frac{1}{2}$ cwt., at from 200 to 250 feet per minute = $1\frac{1}{2}$ actual H.P., the maximum I.H.P. of the steam engines being about 5 on a weight of 14 cwt. Being placed on the boat deck, machines of this class may well be electric, and as the motors will run at higher speed than steam engines no increase of weight need be involved.

Ventilating Fans

are employed for ventilating all compartments below the protective deck and some of the compartments above that deck, such as mess and living spaces. The general practice up to 1898 was to provide six 5 ft. 6 in. double-breasted steam fans on lower deck, three at each end of ship, driven at a maximum speed of about 400 revolutions per minute, and connected together to main ventilating trunks, besides an auxiliary system of ventilation with one 4 ft. 6 in. fan at each end of the ship. The electric driving of ventilating fans is now common in most navies. Fig. 32 shows a Sturtevant fan with open-type motor as used in the U.S. Navy.

In a few recent ships, electric fans of from 3 to 4 feet diameter have been fitted taking about 7 H.P. at 600 to 700 revolutions per minute, the same number (8) being employed and connected to the same system of trunks as designed for steam fans. Figs. 33, 34, and 35 show a 3 ft. 9 in. electric fan of this sort designed by the author and fitted in the I.J.B. "Shikishima." These fans have been adjusted to deliver 7,500 cubic feet of air per minute,

each at 2 inches pressure at 480 revolutions per minute, at which output they consume 5 E.H.P. apiece, but their speed and output can be increased if desired.

Experience has shown that the matter of ventilation has been somewhat overdone in recent years, such powerful

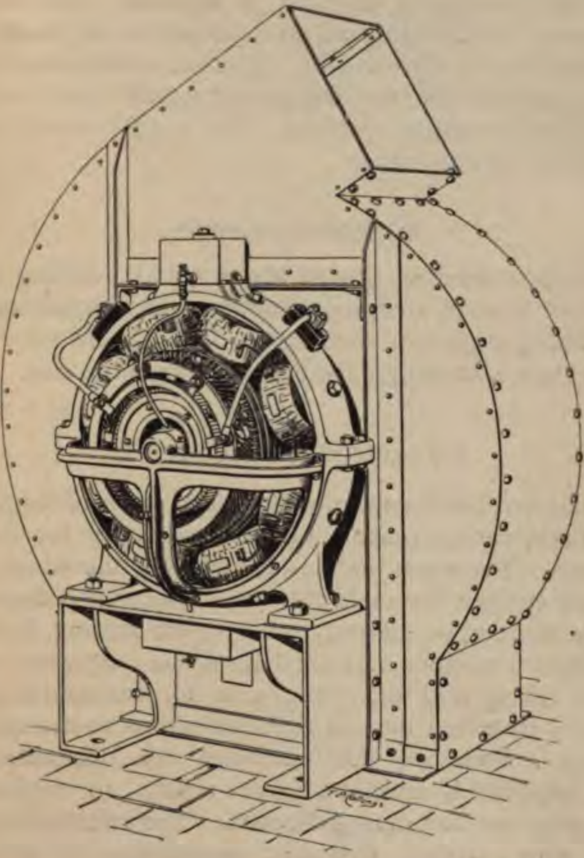


FIG. 32.—Sturtevant Blower, with General Electric Co.'s (U.S.A.) Motor.

fans being seldom worked at their full speeds and powers. Accordingly, in the latest British ships, *i.e.*, all designed since 1898, a larger number of smaller fans with shorter and simpler trunks are employed. The "Duncans," for example, will each carry fourteen fans not exceeding 24 inches in diameter, with motors of about 2 B.H.P.

delivering 1,500 cubic feet of air per minute at 2 inches pressure.

Air Compressors for Torpedo Work.

A modern first-class battleship carries usually four sets each capable of delivering 30 feet of air compressed to 1,700 lbs. per square inch in 70 minutes. This involves an average B.H.P. of about 50 to 60 per set of pumps on a little less than 3 tons weight. Electric compressors would involve quite a different design, but would result in much quieter and smoother working. The weight would remain approximately the same.

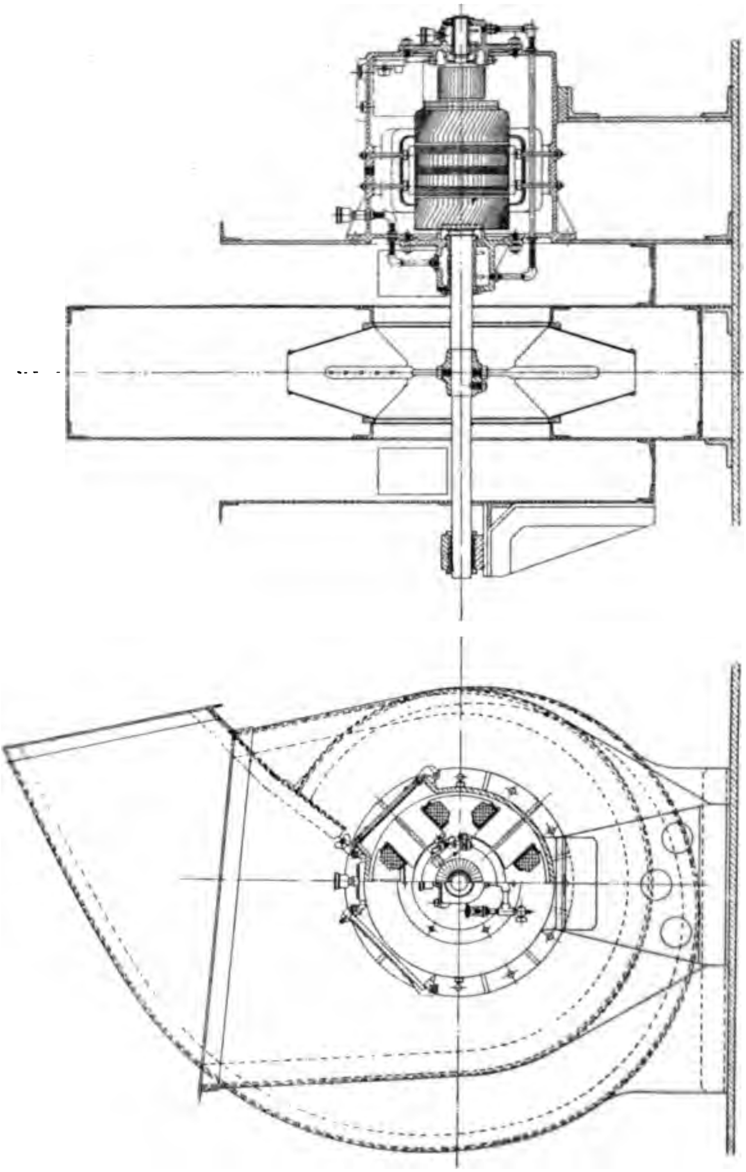
Workshop Engine.

This is a small engine of about 5 H.P., driving one or two short lines of shafting actuating half a dozen machine tools in the engineers' workshop. It is an obvious case in which electric driving is handier than anything else.

Gun-working Mechanism.

A modern battleship, mounting two pairs of large guns *en barbette*, carries quite a nest of machinery for working the guns. There are engines for training the turret, independent engines for each gun for elevating and depressing and for running in and out, rammers for loading, hoists for bringing up powder and shell from the magazines below, besides lifting and traversing gear for transporting shot and shell from the bins in the shell-rooms to the handing-up cage. Some of the machines are duplicated and some triplicated, and there are always in conjunction hand-gears for continuing the work if the mechanism fails.[1] In a ship carrying hydraulic mountings the power is supplied by a steam-hydraulic pumping engine of about 250 I.H.P. situated below and adjacent to the barbette. A pump in the barbette itself is used for circulating the water in the pipes under pressure for use over and

[1] Illustrated descriptions of the turrets and gun-mountings of several British and foreign ships are given in a paper entitled "The Rise and Progress of Rifled Naval Artillery," by Sir Andrew Noble, K.C.B., F.R.S. (*Proc. Inst. Naval Architects*, 1899).



FIGS. 33 AND 34.—Ventilating Fan and Watertight Motor, H.I.J.M.S. "Shikishima" (Thames Iron Works).

[illegible]

[illegible] H.M.S. "Terrible." In the [illegible] armament [illegible] carried, but the [illegible] able to train the turret [illegible]. The pump referred to [illegible]

[illegible] electricity has been more [illegible] steam, earned in the [illegible] quickness of action and [illegible]. The "B[illegible]," which carries two 8-inch [illegible] 13-inch turrets, had two turret [illegible] steam and two by electricity, which favoured a direct comparison. The electric turrets are said to have been started and stopped thirty-seven times in a minute and to have been capable of very small motions at a time. The [illegible] of the electric motors in the first [illegible] led to their extended use in later ships, and in the "[illegible]arsarge" and "Kentucky," not merely are the turrets [illegible]d, but [illegible] guns are elevated and the ammunition

hoists and rammers worked by electric motors. At the present time there seems to be a revulsion of feeling against electric installations. Lieutenant Norton (speaking apparently on behalf of the American constructors) said[1] that in the new large triple screw ships being designed for the United States Navy it has been decided not to use electrical power in the turrets except for the hoist, for the reason that "you can tell what is the matter with a steam or hydraulic engine instantly; but you may chase for hours to find a broken circuit, and by that time the action is over and you are out of the deal." To understand this remark the difference in the character of American and English installations must be borne in mind.

For controlling turrets the Americans use an ingenious method devised by Mr. Ward Leonard, which may be fittingly mentioned here. In the turret is a motor (or a pair of motors in parallel) separately excited at constant voltage; its armature is directly connected with that of a generator in the dynamo-room which is steam driven at constant speed in a field of which the excitation can be varied from maximum to zero, reversed and increased to a negative maximum. The voltage of the generator accordingly varies as its field varies, and the motor armature receiving this varying voltage while its field remains constant, its speed will vary in a corresponding manner. The regulation of the generator field is effected from a controller under the sighting-hood in the turret. The control is said to be extremely sensitive and precise. Retardation is effected with smoothness and rapidity by dropping the excitation of the generator to a point which gives a voltage below that corresponding to the speed at which the motor is at the instant moving; the latter immediately begins to generate current, and therefore quickly absorbs the kinetic energy of the turret. In the latest ships the current so generated is taken up on a braking resistance.

Most nations are now employing electricity to greater or less extent in turrets. Even Sweden is building cruisers in which the working of the turrets and guns is entirely electric. Among the best examples of electric turrets are

[1] Discussion on *Admiral Melville's* paper, "The Logical Arrangement of the Motive Power of Warships," Inst. N. A., March, 1899.

[illegible] H.P. [illegible] be used [illegible]

[illegible] in connec- [illegible] pretty clear that the [illegible] electric working. [illegible] turret designed [illegible] success. If the [illegible] power, weight [illegible] employing electrical [illegible] and strength are [illegible] of the turret when [illegible] while turning; but [illegible] the aggregate power [illegible] the order of 100 [illegible] under worst con- [illegible] in motor capacity [illegible] possible, the motors with [illegible] certainly show [illegible] aggregate weights [illegible] while the weight of [illegible] transmission pipes about [illegible] weight of the electric [illegible]

ELECTRIC AMMUNITION HOISTS.*

For serving the 6-inch and smaller guns are in use in many navies. The "Powerful" and "Diadem" classes of cruisers were fitted with them, but the later English ships are fitted only with hand gears. In the United States and Japanese ships they are usually found. The apparatus consists of a

* See detailed description in Engineering, [illegible] 1895.

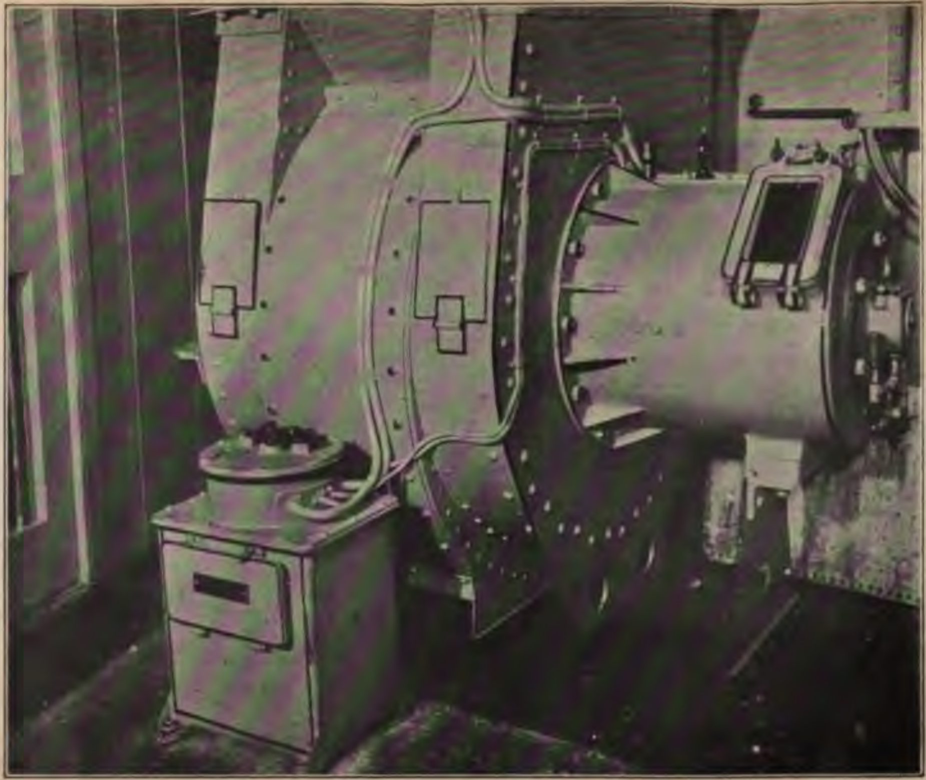


FIG. 35.—General View of Motor Fan and Controller, H.I.J.M.S. "Shikishima."

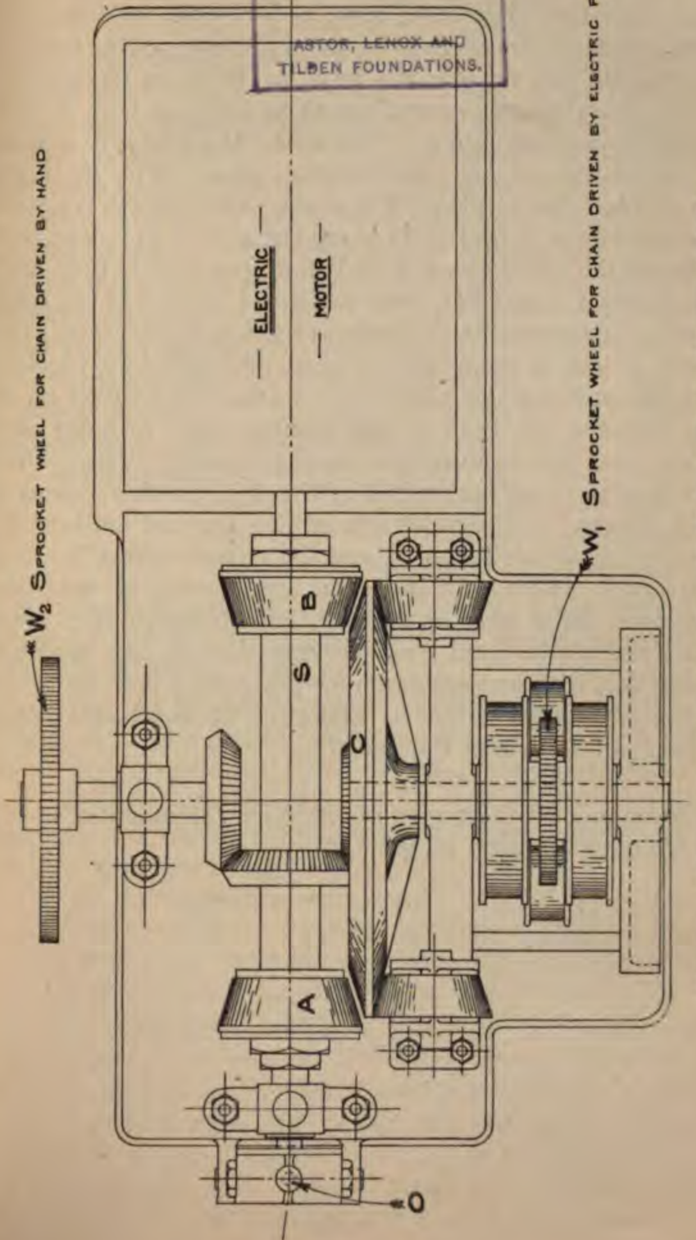


FIG. 36.—Electric Ammunition Hoist Gear (Sir W. G. Armstrong, Whitworth & Co.).

quick-running motor of 2 to 5 H.P. geared in some way to a light whip or chain tackle for lifting small parcels of shot and shell at high speed. The motors must be so controlled that they start, stop, and reverse very quickly, with automatic brakes to hold them as soon as the current is switched off, or else the motions must be effected by clutch gears thrown in and out of connection with a continuously running motor. The latter arrangement is used by Messrs. Armstrongs with friction gears. Fig. 36 shows the arrangement in plan. The motor shaft being in rotation, a vertical lever acting at O along the axis of the shaft puts either of the speed cones A or B into gear with C, thus driving sprocket wheel W1, over which an endless chain runs, passing also over a fixed sheave at the top of the hoist. The cones A and B being out of gear, and therefore running free, the cartridges or projectiles in a bag are hooked on to the chain at the bottom, the friction gear brought into action, and the ammunition rapidly hoisted. Then, while this bag is being unhooked at the top, another round is being hooked on the other side of the chain at the bottom, the cone gears are reversed, and the second charge hoisted, and so on. There is an automatic arrangement for throwing the cones out of gear at the right time for each lift; there is an alternative hand gear working through the sprocket wheel W2, with arrangements for preventing both the hand and power gears being in operation at once, and other details not shown in the sketch.

Summing up the power requirements enumerated in the foregoing paragraphs we get—

	Total Motor Capacity Installed, including Duplicates. E.H.P.	Maximum demand for Power, Duplicates excluded. E.H.P.
Ship ventilating fans	40	... 40
Engine- and boiler-room fans ...	100	... 100
Furnace air-blowing engines ...	200	... 200
Steering engines	400	... 200
Forward capstan	120	... 120
After "	50	... 50
Boat hoists	100	... 100
Coal hoists	100	... 100
Ash hoists	20	... 20
Workshop engine	5	... 5
Air compressors	200	... 100
Turret motors	500	... 300
Ammunition hoists for 6-inch and smaller guns	50	... 50
Totals	1,885	1,385

If these figures err, they err on the large side. In working out details, savings both in power and weight could probably be effected.

There are no conceivable circumstances in which the whole of these machines could work simultaneously. The worst conceivable case supposes that in time of action all the gun-working machinery, air compressors, furnace engines, ash hoists, ventilating fans, and steering engine would be at work together.

Then the aggregate horse-power demanded would be, according to the above figures, 1,015 E.H.P. input to motors = 760 kilowatts. The lighting of the ship would involve 50 kilowatts, and the searchlights—if it be conceivable that all this mechanism could be employed at night when searchlights were wanted—a further 50 or 60 kilowatts. But, taking into account the fluctuating demands of current made by the motors, and the fact that it is hardly physically possible for everything to be working at the top of its load at precisely the same instant, about 600 kilowatts output *would meet all requirements* and cover distributing losses,

[illegible] advantage of [illegible] ships, and the [illegible] the relative [illegible] evenly balanced. [illegible] been introduced [illegible] on their coast defence ships "Buda-[illegible]" [illegible], and "Monarch," the currents being generated [illegible] machines which give continuous currents from

a commutator on one end and three-phase currents from collecting rings at the other end of the armature.

(*b*) The question of the voltage standard is of greater difficulty. 800 kilowatts at 80 volts means 10,000 amperes to distribute, which represents a very formidable amount of cable work. If the pressure were doubled, the currents would be at once reduced to 5,000 amperes and the saving in weight and cost of cables would be material. The United States battleships "Kearsarge" and "Kentucky" are wired on the three-wire system with 160 volts between the outers. The motors are in general arranged on the 160-volt mains, though a connection is usually taken from the middle wire to provide for changes of speed by switching the motor on to the low-voltage mains. Searchlights and incandescent lamps are arranged on either side of the system to make an approximate balance, as is usual. The results of experience in these ships will be watched with great interest. The author is a little diffident as to the introduction of a three-wire system on board ship, and would rather prefer a direct circuit of 160 volts for both lamps and motors. Indeed, having got so far, one might as well accept the 200-volt standard at once. Searchlights in such an installation could be operated with very little complication through "series-parallel" switches, which, in the one position, would put two searchlights in series, and in the other position put each searchlight on separate circuit on the mains, with the addition of a resistance capable of absorbing the remaining volts. With automatic lamps, this should be quite feasible, and any difficulty attending the use of so large a resistance as would regulate the arc down from 160 or 200 volts would probably be less than the difficulty of maintaining a balance of voltage on the two sides of the three-wire system when the searchlights worked intermittently, if that system were used. Of course the use of 200 or even 160 volts generally would impose a greater strain on the insulation of the cables and fittings than is now experienced, and would require some improvements in the design of fittings established; but there are no serious difficulties here.[1]

Instead of the Tree system of wiring as at present

[1] Between the dates of printing and of reading the paper, the Admiralty issued a circular to the effect that 100-volt dynamos would be used instead of 80 volts in future ships, beginning with some laid down in 1899.

[illegible] by the saving [illegible] machinery [illegible]. The weight [illegible] a credit against [illegible] indeed be a slight [illegible] cables and switchboards [illegible] exhaust pipes now [illegible] in question, but it would not be [illegible] tons of additional weight, then, [illegible]. In discussing the question of coal consumption [illegible] was shown on the figures there stated that the

substitution of electricity for steam for all the auxiliary services, would result in the saving of 262 tons of coal for every 25 days' steaming. This figure was calculated upon data assumed to represent the best possible conditions. Some of the engine- and boiler-room pumps have been assumed to remain steam-driven, but if electric driving be applied to the services enumerated and if only one-half or one-third of that estimated saving were realised, there would still exist a strong *primâ facie* case for the adoption of electrical power.

The weight of generators might be materially diminished by the employment of single-acting engines driving dynamos at higher speed, and still more by the adoption of turbine-driven sets;—the weight of the units mentioned could be done with Parsons turbo-generators, including condensers for about 60 tons. Single-acting engines and turbines have both been used in the Navy; unfortunately both have failed, and, as a consequence, both are at present looked somewhat askance at for the purpose. They require dry steam: hence one of the principal sources of difficulty in the old arrangement, but one that should not occasion much trouble in the new. This consideration, coupled with the very great improvements that have been made in both since the days when they were used in the navy, may bring them into service again.

The space required for the generators for the power mentioned would lie between 800 and 1,000 square feet, whichever of the three systems be adopted. It is not easy to find this room in an existing battleship; but on the hypothesis, the main hydraulic engines would not be wanted, and the space occupied by these two rooms would be available. If in consequence of savings on account of efficiency less coal were carried, though a saving of weight would be appreciated, little space would be added for the purpose of generators. Possibly the change to electric driving might be carried out in conjunction with some other change in the disposition of the *matériel* in the ship. For example: there are not wanting critics who consider that it is out of place in these days for ships of the fighting line to carry torpedoes. Should such a view obtain official support, a room equivalent to one of the existing submerged torpedo rooms would make an ideal generating station. Its locality

would be, for preference, immediately adjoining the forward boiler-room bulkhead, so that the steam connections might be short and direct.

The electrical equipment of ships of war is the product of many hands and brains. Naval authorities do not as a rule design—they formulate requirements, and the engineering experience of the country is laid under tribute to meet those requirements. Hence it comes about that much of the apparatus employed is of a proprietary kind, and the author has to acknowledge the kindness of many firms and friends who have allowed him to describe their apparatus and inventions. These have already been mentioned by name in the paper. He is also under obligations of a more general kind, and is pleased to acknowledge here his indebtedness to the Lords of Her Majesty's Admiralty for permission to describe parts of the equipment of H.M.S. "Albion" and to make various references to Admiralty specifications; to the Naval Attaché of the Imperial Japanese Embassy, for permission to refer to the equipment of the battleships recently built in this country for the Japanese Government; to the General Electric Company of Schenectady, U.S.A., for the photographs illustrating American apparatus; to Messrs. Sir W. G. Armstrong, Whitworth & Co., Ltd., for permission to include particulars relating to the electrical side of their naval ordnance work; and to the Directors of the Thames Iron Works Shipbuilding and Engineering Co., Ltd., for permission to make general use of the information in their possession.

Captain Creak.

Captain E. W. CREAK, R.N.: The only question I should like to refer to with regard to this paper is that of the wiring affecting the compasses. I know of but one occasion on which the wiring has ever affected the compasses, when in a projector the two arms which divide the wires had the current passing up one arm and returning down the other; the consequence was that when the projector was turned in one direction we had an error of 2° that way, and when it turned the other way we had 2° in the other direction. The error was prevented by leading both the wires up one arm and making the rule that no projector should be brought within 9 feet of the compasses. There are two sources of disturbance, one of which is the wires (but I do not think it has ever been brought home to them), the other and chief sinner, is the dynamo. I have been asking the designers to

Captain Creak.

give us a dynamo which shall not have an external field. Those we have hitherto used in the Navy, until multi-polar machines were introduced, have been, as regards waste lines of force, bad—the early ones very bad indeed, expending much energy which might be used for lighting the ship. When the armour-plated dynamo was introduced we were told that, at 10 feet, we should not get any disturbance, but at this distance we had a deflection of 60°, although at 53 feet we hardly felt it. In this case it was in a line with the shafting that we got the disturbance. In another position, abreast, at a distance of 28 feet, we still had an error of 2½°. The wiring has been the subject of experiment for many years past. Insulated returns are used, and in early days it was determined that the lead and return should always be coupled together—indeed, you will find no ship except the *Polyphemus* in which this practice has been departed from.

To illustrate the possibilities of error that may occur, I may mention an instance in which an officer had a twin lead for lighting his compass in the binnacle. The twin lead carried away. He then put in two wires but did not couple them together. There was then a disturbance of 4°. He searched all over the ship for the cause of the disturbance till I happened to go on board, when I found the lead and return wires were lying loose in the binnacle: sometimes coming close to the card and sometimes away from it!

Mr. Evershed.

Mr. S. EVERSHED: Mr. Grove's paper appears to be one of great value from two points of view. It gives a good account of the transitional position of the use of electricity in the Navy, and that account is necessarily interesting to us as electrical engineers. But I venture to think it is also of interest to us as Englishmen. We are glad to see that our own Navy is not so far behind the Navies of the rest of the world. There is a prevalent idea that in the British Navy every novelty is opposed as a matter of course, but those who have had anything to do with introducing novelties into our Navy know that this is not always the case. A novelty, it is true, has to pass the ordeal of the three great branches into which the administration of the Navy is divided —first, the general administrative branch, then the constructive branch (including all the departments concerned in designing, building, and arming our warships), and finally, when it has got through these two it goes to sea and meets with the executive branch. You might call those branches, for short, the obstructive, the constructive, and the destructive. I do not use the term "destructive" in a derogatory sense; in time of war it is the business of the naval man to destroy the enemy's fleet, and in times of peace he destroys a few other things.

In regard to magnetic leakage from the dynamos, to which Captain Creak has referred, I was aware some years ago that it was proposed to try iron-clad dynamos, and I felt perfectly certain it would be a failure. I ventured to put my views before the Admiralty in an unofficial way, but I do not think they had very much effect. It was felt that this form of dynamo ought to be tried, and it was tried. I am not at all surprised to hear that it only diminished the compass error by about a half. The reason is that, although you can to some extent stop leakage from the pole-pieces of a dynamo, you can never get

Mr. Evershed.

entirely rid of the effect of the field-coil by putting iron roun
When you want to shield a place from magnetic influences you
put the shield round the thing itself. The compasses canno
shielded, and you cannot prevent the compass being disturbe
putting an iron shield round the field-coil. By introducing four-
dynamos, the Admiralty has found the true way out of the diffic
because they are making the dynamo astatic.

It is clear, from Mr. Grove's paper, that in regard to the applica
of electricity, warships are in a transitional stage, and the next
years will see an enormous difference in the manner in which elect
work is carried out on board ship. At present, on examining a war
from the electrical engineer's point of view, one is struck with
rather casual electrical arrangements. All the dynamos, eng
cables, and appliances generally, are of the best possible quality,
the manner in which they are put into the ships rather suggests
the whole of the electrical scheme was of the nature of an after-thou
I think that Mr. Grove's suggestion of a power station on board
vessel, or, at all events, each first-class cruiser and first-class battle
is the right one. In a few years time we shall see a position for
central electrical power station carefully designed and put into
right part of the ship under the protective deck.

Mr. Grove very truly says that the development of the warship
been the product of many minds and of many men's work. Mo
the novelties which have been introduced have been introduced f
the outside, and my own part in the work has been in the direc
of establishing various communications on board ship. There ar
Mr. Grove points out, several means of communication. I can con
what Mr. Grove says as to the unsatisfactory nature of voice-pipe
speaking-tubes. It is almost impossible in many parts of the shi
make any use of these pipes. They exist, but no one who has no
enormously powerful voice can make himself heard, and the ma
the other end can very rarely hear at all unless there is abso
quiet prevailing. To take an example: from the tiller compartm
you may try and communicate wlth the fore-bridge. I have on m
occasions had a bluejacket to speak for me, and he has endeavoure
communicate and has failed. He has failed simply because he c
not hear the reply, there being so much noise below even when
ship was in dock; there is the noise of auxiliary engines, or the stee
engine may be at work, and anything of that kind completely prev
any one from hearing. The loud-speaking telephone will be a valu
improvement on the voice-pipe, because it will enable a man to
heard almost as clearly as though he were standing beside one.

In addition to the voice-pipes on board a warship there are
course, various telegraphs; as Mr. Grove has described, there
instruments indicating the position of the helm at various parts of
ship, others for telegraphing to the engine-rooms the number of rev
tions per minute, and others, again, for signalling the range of the ene
and so on. On the table are some electrical means of doing all th
things. Roughly speaking, the electrical means of communication
board ship, for these purposes, may be divided into two broad cla

there is the apparatus which contains a good deal of mechanism and is worked by a very small amount of electricity, and there is, secondly, an apparatus which takes a good deal more electricity, but contains practically no mechanism. The apparatus which Mr. Grove has described shortly on page 564, and which was developed by Mr. Richards and myself some years ago, belongs to the second class. It consists practically of a very powerful ohm-meter. The handle which forms the transmitting arrangement simply alters the resistance in the circuit. There is nothing to get out of order, and the only moving part of the indicator is the needle, of which there is a sketch on page 565. On the same page is a skeleton drawing showing the construction of the ohm-meter. This apparatus can be worked at any desired speed, whereas apparatus of the kind which contains a good deal of mechanism and uses a very small amount of electricity requires the introduction of various devices in order to prevent people working it too quickly. Nothing can make the ohm-meter arrangement get out of order. These instruments have been employed for the last eight years on some of the ships, and so far not only have we had no failure, but we have had no repairs and no adverse reports of any kind whatever. On one ship, the *Narcissus*, the apparatus was used while the ship served two three-year commissions on the China station, and on the return to Portsmouth the apparatus was practically as good as new. There is on the table another apparatus, substantially the same as the engine-room telegraph, which provides a means for communicating to the bridge the angle at which the rudder is placed. The last apparatus, to which reference is made and which is not yet introduced, is for signalling either to the engine-room the revolutions per minute which the engines are to make, or to the guns the range or any other figure which the gunners require to know. The instrument on the table is fitted up as a revolutions telegraph. The indicator contains as many ohm-meters as there are signals, but they are all coupled in series so that they only require one four-core cable to work on. The instrument is read in the same manner as a thermometer, and the number of distinct signals, or digits in a number, which can be shown on the dial is practically unlimited. Mr. Evershed.

Mr. R. E. Crompton: Although I understand there are several officials connected with the Admiralty now present, I will take the risk of doing as I did seven or eight years ago when a paper on the same subject was read before the Institution of Mechanical Engineers at their Portsmouth meeting, and that is to take the opportunity of criticising somewhat severely the Admiralty proceedings in regard to employing electricity in the navy. Mr. Crompton.

I have been informed by Sir William White that my Portsmouth remarks were of some service, and there is no doubt that some improvement has taken place, but much more might be done if the Admiralty treated modern electrical developments in a serious spirit and appointed a staff of electrical engineers of standing and experience to advise them and to work out for them the difficult problems that arise out of the complicated arrangement of modern battleships. I think Mr. Grove's paper is a valuable one. He has laid before us in a convenient

Mr. Crompton.

form the various methods of employing electrical plant on board Her Majesty's ships and compares it with what has been done in other services, and I think the meeting will agree with me that the paper is practically an indictment of our Admiralty proceedings. The Admiralty began badly. My firm were contractors for the whole of the electrical equipment of the Brazilian warship the *Aquidaban*. We then arranged for the first time the general features of the modern equipment, that is to say, direct-driven dynamos, projectors with mirrors hung on springs, spring attachments for incandescent lamps and the bulkhead and other light fittings which have since become so familiar. Our work on the *Aquidaban* was inspected on behalf of the Brazilian Government by an Admiralty official, and it is a curious thing that, within a short time, from his office emanated the first of Admiralty specifications for electrical apparatus for naval purposes. In those specifications a great many of our ideas were annexed, and from that date to this no acknowledgment has ever been made to us. To take a concrete case of Admiralty backwardness: for years past they have employed projectors having long-focus mirrors and inclined hand-lamps. The combination makes the projector inferior to those used by any Continental Government. It has been long known that the only way to get a steady reliable arc is to use an automatic lamp with horizontal carbons and with magnetic means of deflecting the arc flame; but with this form of lamp it is absolutely necessary to have a short-focus mirror; for the Admiralty 24-in. projector this focal length should not exceed 12 inches. With the long 17-in. focus mirror employed by the Admiralty the shadow of the negative carbon is so large that a considerable percentage of the centre of the mirror is useless. The result is that the beam projected is not solid but tubular. All this has been known to foreign Governments and to our War Office, who have long since adopted the horizontal type with the short focus.

Then s regards automatically-controlled projectors. These are used by foreign Governments. My own firm have made such for the Japanese Government, and they have given excellent results, but no use is ever made of this class of apparatus by our own naval authorities.

Turning to the last and most important part of the paper, namely whether or no the electrical requirements of a warship should be considered much as we should consider the electrical requirements of a town supplied from a central station; this was precisely the subject of my remarks at Portsmouth, for which I was thanked afterwards by Sir William White. It is evident that the author of the paper and Mr. Evershed, among other speakers, agree with me, that this is the standpoint from which the Admiralty should regard the supply and distribution of electric light and power. It is evident that it is a far simpler and better job to supply power to the whole of the complicated auxiliary machinery of a modern battleship from a central station located below the water line, the generating units being of such size as to be conveniently duplicated, and the distribution system being interconnected and duplicated to such an extent as to render it impossible for the service to be interrupted at any point by damage to the mains [illegible] to the enemy's artillery or torpedoes or by ramming. It is evidently

Mr. Crompton.

a much easier and simpler task to teach the use of the electrical motor as a means of supplying power for any convenient purpose, than it is to teach the use of several kinds of motors, such as hydraulic, oil engines, steam engines, compressed-air engines and the like. I know that my friend Mr. Campbell Swinton will urge that electric motors cannot be arranged to train heavy guns so well as can be done by hydraulics, but I think in this he is wrong. He has not sufficiently considered the very perfect arrangement devised by Mr. Ward Leonard to which I called public attention in my presidential address five or six years ago. This very beautiful invention has not been used or understood by engineers nearly as much as it ought to be. It is certainly the most beautiful variable-speed torque arrangement that has yet been devised, and I understand in actual practice it is found to enable guns to be trained within minute fractions of a degree, in fact even more minutely than can be done by hydraulic motors. Mr. Grove points out with truth that even now on board ship the electric motor is looked upon with suspicion—steam they know, hydraulic power they know, but electricity they do not know much about. May I ask who are the *they* who find it difficult to understand the modern electric motor? I ask you gentlemen in this room which class of motor could be the most easily explained to the average man-of-warsman—the electrical, the steam, or the hydraulic motor, and in actual practice which breaks down more frequently? I think every one will admit that the electric motor is far superior in this and many other respects. It never breaks down suddenly; if it is worked badly it gives signs of it by vibration or by sparking at the brushes, and the fault can be readily taken in time and remedied; but with other mechanical motors the breakdowns that do occur are generally sudden and likely to occur just at the time when they may be of most serious consequence. Again as to the liabilities of heavy maintenance charges of electric as compared with hydraulic motors. We have a ready means of comparison in the case of these in the shape of hydraulic lifts as compared with electric lifts in private houses. I have had a hydraulic lift in my own house under my own eyes for the past ten years, and I can say with confidence, that what with the packing of glands, refacing valves, and other matters peculiar to hydraulic systems, my hydraulic lift has taken ten times the attention that would have been necessary if it had been an electric one. Of course, the other matters of repair, such as the wear and tear of ropes, lubrication of guides, etc., are common to both systems, and therefore, in comparing them we have only to compare the hydraulic system of providing power with the electric system.

As regards working searchlights with 200-volt circuits, I think the proper way of doing this is by rotating transformers. I observe that on the last page of his paper Mr. Grove states that engines and turbines have both been used in the Navy and have unfortunately failed, and as a consequence both are looked somewhat askance at for the purpose. I think it is well known in this room why the single-acting engine failed in the Navy. There must be something wrong when *the single-acting Willans* engine, which has been such a great *success for all central stations* for the supply of electricity, was found

Mr. Crompton.

inapplicable for naval purposes. The reason why these engines were not acceptable in the Navy is not a creditable one, and the less that is said about it the better.

Mr. Richards.

Mr. A. E. RICHARDS: The paper under discussion, although termed "Electricity on Warships," deals naturally very fully with the practice in British warships, and it is some satisfaction to all those who have been associated with this work to find that, in comparing our system of electric lighting with the system in foreign navies, Mr. Grove states that "none of these methods appear to be so safe and so thorough as the British Admiralty method of lead-covered cables, closely packed together, and visible and accessible throughout their length." This opinion is all the more valuable coming from a gentleman who is one of the very few who have had practical experience with this branch of the profession. The following remarks on the details of the paper are intended rather to be supplementary to the mass of information so carefully collected by Mr. Grove, than to be critical.

The British Admiralty practice as regards generating plant is fully described, and it is stated that the temperature clause of the American specifications is 50° F. as against 70° F. of our service; this is interesting because, when this Admiralty specification for dynamos was first published, it was discussed and fully criticised at a meeting of this Institution, and strong views were expressed as to the low temperature permitted. Experience has fully justified the temperature-rise adopted in the specification, and I may state that of all the dynamos (1,000 sets, amounting to nearly 30,000 E.H.P.) purchased by the British Admiralty under this specification, I have known only of one case, in the very early days, where the electric-light machinery has had to be removed in consequence of defective dynamos. Dynamos have worn out their engines, and engines and dynamos have survived the main machinery, and we have now in working order on our ships several sets of electric-light machinery originally fitted in ships as far back as 1886, but now removed and fitted in other ships. This, I think, settles the question of the durability of electric machinery. It is, perhaps, somewhat unfortunate that electric power should have been first introduced into warships for lighting purposes, as any slight hitch is at once evident to every one from admiral to cook, and no matter to what (engines, boilers, etc.) this hitch was due, it was at once put down to the electrical arrangements being unreliable.

Mr. Grove refers to the disturbing influence of dynamos on compasses, and makes a remark which might be construed to mean that this is a recent discovery. Very far back, however, certainly before 1884, experiments were carried out on H.M. ships which left no doubt as to this effect on compasses, and in 1886 experiments were made on H.M.S. *Northampton* to determine accurately this effect. The increase in the power of dynamos in modern ships and the alterations in the compass arrangements has made this question prominent lately; but as regards the Admiralty service, no difficulty has been found in correcting any effect of this nature.

As regards Mr. Grove's remarks on the details of our fittings, the lampholder was introduced at a time when lampholders were a

monopoly; the cost was 2d. as compared with 2s., and there are probably 500,000 of these in use in our own and foreign navies, and experience of many years shows that the slight difficulties anticipated by Mr. Grove are unimportant in practice. Mr. Richards.

With reference to parallel working of dynamos, this of course presents no difficulty, and if any large extension of electrical appliances be adopted in H.M. Navy, it will no doubt be done. The searchlights, as the writer remarks, form an important feature in the armament of warships, and the Admiralty Projector has been severely criticised by Mr. Crompton, and I think Mr. Crompton's remarks show plainly that it would be very risky to allow such important questions as the electrical equipment of warships to be dealt with solely from the electrical engineer's point of view.

Mr. Crompton says, use short-focus mirrors; but all our experience shows that with a shorter focal length than we at present use, the mirror invariably cracks. Mr. Crompton advocates electrically controlled projectors and automatic lamps. The experience of the Americans in their late war is as follows: "The automatic controlling devices of searchlights were totally useless in action, and all these devices are being removed. When a steady beam of light is demanded, the automatic lamp mechanism fails to meet the requirements, and it has been found necessary to feed the carbons by hand." This American war experience agrees very closely with the conclusions arrived at by our officers, who have conducted an immense number of trials with all sorts of such appliances. Further, as regards Mr. Crompton's remarks as to the *Aquidaban*, although I have been connected with this branch of the work at the Admiralty for many years and practically the whole of the present specifications have been drawn up by me, I have absolutely no knowledge of what was done by Mr. Crompton on that vessel, and I am sure that our present system has nothing in common with the system on that vessel.

I notice on page 547 a little fitting for automatically indicating when bow lamps are burning; this fitting shows the suspicion of unreliability, which electrical appliances always meet in ships, and in the very early days (1884) a similar fitting was fitted to the bow lights of H.M.S. *Crocodile*, but it was found that the bow lamps, properly fitted, did not fail, and the arrangement was abolished.

The general system of communication discussed is that at present used in the British service, and, although it is now simple and efficient, the fittings being reduced to a bell-indicator and push, this system has not been arrived at without an immense number of experiments. Trials have been made for years with all sorts of telephones and instruments, but they have not proved satisfactory. I am, however, pleased to say we have at last arrived at what I hope will be an entirely satisfactory telephone, that by Mr. Graham, and I am sure Mr. Graham will readily admit the assistance, in developing this instrument, he has received from the Admiralty service.

With reference to electric telegraphs, we have had endless trials of all sorts of instruments for this purpose. These instruments invariably give satisfactory results at first, but quite fail to stand the strain of sea

Mr. Richards.

service, and ordinary electrical instruments are entirely useless on shipboard. The telegraph instruments on the table Mr. Evershed has described, and also gives some information as to the length of time these instruments have stood the test of sea service, which is creditable to the makers; but as the circuits and fitting up of these instruments were carried out by the Dockyards, this is also, at least, a slight testimonial to the excellence of the electrical work done in these establishments. I may add that the American experience of all delicate electrical instruments, either as telegraphs, range-finders, or telephones, is very decidedly against their use.

Coming now to that part of the paper dealing with electric power, the writer does not propose to fit motors to the auxiliary machinery co-operating with the main machinery, in deference to present engineering opinion. This really means that the only electrical machinery for continuous working will be the fans, which are a very easy and suitable application of electrical power; these are already largely used in H.M. Navy, and in future the whole of the fans for ship ventilation will be electrically driven, the fans for engine and boiler rooms being for the present steam driven.

Now as to the application of electric power to working guns, upon this the general question of the application of electrical power will be largely decided, as it would not be practicable to fit a ship with hydraulic power for guns and electric power for other purposes. It will be necessary as a first step to convince those officers who have the practical working and management of the guns, and who are responsible for the fighting-efficiency of the ships, that electric power is more satisfactory than the present hydraulic system (the experience of the American Navy does not favour this view); and I may state that no electrical or gunnery fittings are allowed to be fitted in our ships without having first undergone satisfactory trials by those officers who will have to use them at sea. As far back as 1894 H.M.S. *Barfleur* was fitted with electrical arrangements for working her 10-inch guns, and these arrangements were so satisfactory that the three vessels *Barfleur*, *Centurion* and *Renown* were fitted with an electrical system for working their ammunition-hoists, and these have been entirely satisfactory. The *Capitan Prat* is mentioned by Mr. Grove as a beautiful example of the application of electric power, but I am afraid that in H.M. Navy it would be preferred to carry the one or two men necessary to train the turret, rather than fit electric motors for this purpose. I quite agree with Mr. Grove that all the operations he describes can be efficiently carried out by electric power; but I am not prepared to admit any advantage in weight. An entirely new arrangement of warship design would be necessary; in fact, gun-mountings, turrets, etc., would have to be designed specially for this purpose, and it would amount to designing the ship round a central station. At present we have to take the ships as we find them, and make the best arrangements possible.

I do not propose to follow Mr. Grove in his calculations as to the effect of the adoption of electric power generally on a battleship, as the modifications are so extensive that to obtain really reliable data

it would be necessary to design a ship, as it is not only necessary to provide space and weight for the necessary electric power, but the general effect of the altered conditions must be considered. As an illustration of this, when it was decided to use electrical fans for ship ventilation, it was found necessary completely to alter the usual system of ventilation, and instead of a few large fans 5 to 6 feet diameter, to use a number of much smaller fans. Mr. Richards.

Mr. Grove, on page 602, remarks that Naval authorities do not design. I am pleased to say, however, that the whole of the fittings exhibited here to-night, with the exception of one or two patented articles, have been designed in H.M. Service, although used very extensively for foreign warships.

The Admiralty requirements for electric fans, boat-hoists, and capstans are given in this paper, and I conclude my remarks by giving the results of actual trials with these.

Fan.—Centrifugal, 2 ft. diameter. Output, 1,500 cu. feet of air per minute at 2 ins., water gauge. Revolutions, 900. Current, 11 amps.; volts, 80.

Electric Boat-hoist.—Weight of hoist, including motor, drum, gearing and controlling gear and resistance $=6\frac{1}{2}$ tons. Revolutions of motor, 650. Gearing, worm and wheel, then pinion and spur wheel; total reduction, 150 to 1. Weight lifted, $8\frac{1}{2}$ tons through 15 ft., in 16 seconds. Current taken $=450$ amps.; 80 volts.

Electric Capstan.—Weight of capstan, motor, gearing, and controlling gear $=12$ tons. Revolutions of motor, 450. Gearing, worm and wheel, then spur and pinion. Weight lifted $=15$ tons through 5 ft. in 12 seconds. Current taken, 400 amps.; 80 volts.

Mr. A. A. C. Swinton: I wish to say, to begin with, that I do not agree with all that Mr. Crompton has said. He has, I know, given a great deal of attention to these matters, but so far as electric lighting of warships is concerned I think I may, perhaps, claim equal experience. My very first electrical experience was entirely connected with the electric lighting and electric arrangements of ships of war, and I spent about five years doing nothing else. My view of the matter is that, up to a certain point, the use of electricity for the distribution of power in a ship is very advantageous, but that it is not applicable in all cases. I think, more especially with regard to the training of large guns, that hydraulic power is very much better. The training of large guns demands slow, steady motions, and these can be obtained by hydraulic means with extraordinary precision in a way that I do not think can ever result from the application of any kind of mechanism in which there are rapidly revolving parts. With rapidly revolving parts, such as are necessary with a motor, there must be introduced the effects of momentum, and there must be great complication of gearing and the use of brakes and all manner of appliances in order to reduce the speed and to get the gun to stop at the exact place required. Hydraulic machinery is Mr. Swinton.

Mr. Swinton.

exceedingly well suited for that particular purpose, and, although I am chiefly an electrical engineer, I consider that it would be just as reasonable to try and work a forging press with an electric motor as to apply electricity to the working of a large gun. Mr. Crompton made a point of the liability of hydraulic machinery to be injured by frost. I do not think that this is found in practice to be a serious trouble on board ship. Anyway, hydraulic machinery cannot well be injured by damp or by salt water, which is more than can be said for electrical machinery, while it is easier to keep things on board ship warm than it is to keep them dry. No doubt, as suggested by Mr. Crompton, there would be less for the engineers to learn if everything was done electrically, and hydraulic machinery could be entirely dispensed with. I would point out, however, that even if electricity were applied throughout for all the purposes for which it is possible to use it, hydraulic arrangements would still be necessary for absorbing the recoil of the guns. For this purpose, at any rate, the use of hydraulic cylinders is practically essential.

Mr. Grove, in his paper, has referred to the use of single-acting engines and steam turbines on board a ship. Mr. Crompton has said something on the subject of single-acting engines, and I should like to add a word about turbines, because I was perhaps the first to put turbines for electrical purposes on board a warship—in the case of the *Blanca Encalada*, which was sunk in the Chilian War. During the period I was at Elswick we put a large number of turbines into warships, and they worked exceedingly successfully. After that the Admiralty adopted them, and in a conversation with Mr. Parsons, whose turbines they employed, I asked him to what he attributed the fact that the Admiralty did not continue to use them. We discussed the matter, and we agreed as to the reasons. First of all, steam turbines are not well suited for the small powers such as were then used in ships, as it is very difficult to make small turbines economical. When you get to the larger sizes it is of course a different matter. Another thing was that, in those days at any rate, the electrical part of the equipment of a ship was a very small proportion of the whole, and it was difficult to get the engineers to take sufficient pains to learn the details of a new machine which they only considered a very small part of their business. Thirdly, in some cases, these turbines were placed transversely, across the ship, instead of being placed longitudinally, as they should have been. With turbines placed transversely, and running at very high speeds, there is a very heavy strain and danger of injury to the turbine, owing to gyroscopic action when the ship rolls.

In conclusion, I should like to say that in my opinion this Institution is very much indebted to Mr. Grove for his very valuable and comprehensive paper, the first one, I believe, we have had upon a very important subject.

Mr. Allingham.

Mr. G. C. ALLINGHAM: It would be very interesting if we could have a few more particulars as to how the lead-covered wires stand on board ship. One speaker has told us that he thinks lead-covered wires ought to last as long as the ship. That hardly agrees with what we are told

by some landsmen, especially fire-office inspectors, who tell us tales of how lead-covered wire rots away, asserting that if lead-covered wire is run in the damp cellar of a house the covering is sure to drop to pieces within eighteen months or so. But as the Admiralty has used lead-covered wires for a long time, and still continues to use them, they must have lasted pretty well, and one may fairly assume that the test is a severe one. It might also be of interest to know whether wires or cables with fibrous insulation have been tried at all on board ship. The tendency of practice with street mains nowadays is to abandon vulcanised indiarubber insulation in favour of fibrous insulation, and the same trend of practice is appearing in house-wiring. I should like to know also whether twin cables have been tried for wiring ships. Twin cables would have several advantages over single cables; they would require only half the fixing; there would be only half the number of cables near switchboards and in such crowded places as is shown in Fig. 11 in the paper, and there would be only half the number of watertight glands in the bulkheads and in the distributing boxes and fittings. Twin cables have also the advantage of being safer than two separate wires, for any fault in a twin cable soon develops into a dead short circuit, blows the fuse and cuts itself out. A disadvantage of twin cables is that at least one conductor in each cable would have to cross over or behind the insulating base in the distributing board to reach the opposite pole, but this could be easily provided for by making the boxes a little deeper, so as to allow a space of, say, ¼ in. between the insulating base and the bottom of the box for the wires to cross. None of the wires need cross each other inside the box, nor need any of the cables cross each other outside the box; with single cables, on the other hand, the cables must cross each other outside the boxes, and this is a disadvantage which I think might fairly be set off against the one I have mentioned. Mr. Allingham.

Mr. Evershed has referred to the importance of working instruments as far as possible from the lighting or power mains, and not from primary batteries. In the paper we see that the torpedo-firing circuits are worked by two batteries in parallel at one place, and another high-resistance battery somewhere else; there appears to be a battery on every gun, and there are more batteries for telegraphs, telephones, and so on. All these primary batteries must be a great nuisance, and I venture to suggest that all the instruments and circuits on a battleship should be designed, if possible, to be worked off the mains; or in cases where it would be absolutely impossible to work them direct off the mains, as with telephones, they might be worked with accumulators, charged off the mains.

Mr. A. J. Lawson: One point mentioned by Mr. Grove to which I wish to direct attention is the great length of steam-piping for the lighting engines of ships of war, which are apparently placed all over the vessel, and the wastefulness of this practice. Many years ago, so far back as 1884 and 1885, I carried out a good deal of ship lighting, and on the first visit of the British Association to Canada some of those now present may have crossed Lake Superior on the vessels of the Canadian Pacific Railway Company, in which were installed high-speed Mr. Lawson.

Mr. Lawson. engines and belt-driven dynamos, which one now never hears of on board ship. The speed of the engines was the same as it is to-day, about 300 revolutions per minute, but the dynamos ran at speeds from 1,200 to 1,800 revolutions per minute, according to size. Engines and dynamos were placed on brackets bolted to the frames of the ship within the main engine room and the length of steam-piping was short. Hence, although the engines were anything but economical, I do not think our steam consumption was anywhere near so high as that of present-day practice mentioned by Mr. Grove. A great deal can be done to lessen this wastefulness by adopting a central station method on board ship: there can then be much shorter lengths of piping; and if the Admiralty will use standard voltage machines of 100 or even 200 volts, and not a standard of their own which is not used by anybody else, much of the tangle of cables shown in some of the illustrations can be avoided and the cables may be smaller, while any difficulty with the projectors can be got over by the use of suitable resistances in their circuits or by putting down small motor generators.

Mr. Wilde. Mr. H. WILDE, F.R.S. [*communicated*]: In Mr. C. E. Grove's interesting summary of the uses of electricity on ships of war since its first introduction in the Royal Navy in 1875, I notice under the head of Dynamos a statement that the dynamo installed in H.M.S. *Minotaur* in 1876 was a "magneto machine."

Faraday in his First Series of Experimental Researches, *Phil. Trans.* 1832, p. 138, defined the exact meaning to be given to the term magneto-electricity in the following paragraph:—"58. The similarity of action, almost amounting to identity between common magnets and either electro-magnets or volta-electric currents, is strikingly in accordance with and confirmatory of Ampère's theory, and furnishes powerful reasons for believing that the action is the same in both cases; but, as a distinction in language is still necessary, I propose to call the agency thus exerted by ordinary magnets, *magneto-electric* or *magnelectric* induction (26)."

All machines, therefore, that generate electricity from ordinary steel magnets are, according to Faraday's definition, magneto-electric machines. Now the machines established under my direction on the *Minotaur* and on other battleships in 1875–1880, were self-exciting multipolar dynamos constructed in accordance with the specification of my patent of March, 1867, in which permanent steel magnets were dispensed with. Further descriptions of these dynamos for lighting and for the electro-deposition of metals were published in the *Philosophical Magazine*, 1873, and in other journals. I have already directed attention to the fact that the term "Dynamo-electric Machine" was invented by Charles Brooke, F.R.S., who applied it expressly to my electro-magnetic generator (*Proc. Roy. Soc.*, vol. xv. (1867), p. 409).

Under the heading of Searchlights in Mr. Grove's paper I am reminded of the difficulties I had to encounter in this application of the dynamo, and the important assistance derived from the eminent lighthouse and electrical engineers, MM. Sautter and Lemonnier, of Paris, in enabling me to fulfil the requirements of the Admiralty and War Office Torpedo Committees during the trials of the searchlight on

the gunboat *Comet* in 1874. One of these requirements was that the beam of light from the projector should have, at will, a divergence of 20° in azimuth. This condition was met by the design of the diverging lens now in general use. The design was executed for me by the French optical engineers above mentioned, who also supplied the dioptric lenses used in connection therewith. My electric light regulator with screw motion, patented in 1873, is now adopted in more or less modified forms, in all searchlight projectors. Mr. Wilde.

I may also mention that the general method of searchlight signalling with the vertical beam, by means of a reflecting disc mounted horizontally on a spindle in front of the projector and vibrating the disc by means of a lever handle, was invented and applied by me on the *Minotaur* in 1876.

When the importance of the searchlight as a protection against torpedoes was established, temporary belt-driving from capstan engines was superseded by separate engines, geared to the machines by spur wheels, in order to utilise the low steam pressure ruling in flagships at that time. This mode of gearing soon gave way to the direct driving of my dynamos by Brotherhood's three-cylinder engines (1878–1880) with 60 lbs. steam pressure.

After the year 1880 the alternating dynamos, engines, and projectors used in connection therewith were gradually succeeded by the improved types described and illustrated by Mr. Grove. The absence of French designs of searchlight equipment from Mr. Grove's paper is a notable omission.

Whatever disadvantages the multipolar alternating dynamos of 1875–1880 possessed, which caused them to be superseded in the Royal Navy by those producing continuous currents, the former had the distinct advantage of having no adverse influence on the directive action of the compasses, either directly or indirectly through the wiring of any part of the ship. Should the idea of central electrical stations on board ship be ultimately adopted, alternating dynamos may again come into service both for lighting and motor purposes.

Mr. L. F. NOAKES [*communicated*] : I should like to point out that the vexed question of designing a ship with a central station on board, although only in the imaginative stage in England, has been practically carried out abroad nearly ten years ago. One ship, for instance, mentioned in Mr. Grove's paper, the Chilian battleship *Capitan Prat*, built in Toulon, has a plant of 175 k.w. capacity, the six dynamos being grouped together in a room aft of the engine-room below the protective deck, there being also four switchboards for the control of the artillery lighting and projector circuits, and one for interconnecting the other three. Mr. Noakes.

In reading the reports adverse to the use of electric power in the U.S. Navy, I noticed one of the principal points objected to was the high speed of the engines employed. The artillery dynamos in the above-mentioned ship are driven by a horizontal engine running at 230 revolutions, there being a 500-ampere 70-volt machine direct coupled at each end of the crank shaft. These machines supply 70-volt circuits independently, and in series 140-volt for the armature

currents to the gun motors. The regulation is all that can be desired, the governor being very quick in its action. The total weight of the engine and its two dynamos is about 9 tons. There are two sets, one set being sufficient to move and work all the eight turrets, hoists, etc.

With reference to lampholders, I have had experience with those described in the paper, and also of screw socket lamps with spiral spring holder, as well as others. The spiral spring holder is very much to be preferred, and is quite as secure against breakage by vibration as the loop lamp arrangement. I have, in fact, found on more than one occasion after gun-firing exercise, that vibration sufficient to break the globe has left the lamp intact. There is also a very good holder in the market with small spring hooks for use with loop lamps, but the hooks become brittle through heating and are a source of trouble.

I am in agreement with Mr. Richards when he condemns the use of side and head light alarums; one finds that the alarum apparatus is more often at fault, however simple it may be, than the lamps it is supposed to safeguard. As those on watch on the bridge *must* be there anyway, why add such complications? In considering such apparatus, the old maxim of "It's not what you can do *with*, but what you can do *without*" should not be forgotten.

I do not understand why we should pin our faith to the report mentioned by Mr. Richards, to the exclusion from our navy of such an obviously useful auxiliary as the controller for projectors. I have invariably found that officers have appreciated the value of the control from below of projectors up the masts, especially during gun firing, when I don't think even Mr. Graham's loudest telephone would be of the least use in communicating with the fighting tops, where you have quick-firing guns within a few feet of you.

When speaking of firing circuits, telegraphs and bells, etc., I noticed Mr. Grove did not mention the very successful use that has been made, in recent years, of continuous-current transformers for replacing or supplementing batteries.

With regard to Mr. Grove's remarks about enclosed motors, I can't say my experience of them, as compared with open ones, has always been favourable to them. The enclosed type seems to suffer more from the effects of dampness when disused for long periods. I have found open motors (below the main deck) as good as new after eight years' service and never having required repairs, whilst enclosed motors have given trouble after only one or two years' use.

May I, in conclusion, venture to congratulate Mr. Evershed on his thoroughly practical instruments, telegraphs, etc. I only regret that I have never sailed "ship mates" with any of them; instead, I shall carry vivid recollections of other apparatus with me to the grave.

Mr. Walker. Mr. S. F. Walker [*communicated*]: In thanking the author for his complete and impartial treatment of his subject, I should like to enter a protest against the manner in which the Government are treating the matter of Electrical Engineering. Day by day the use of electrical apparatus on board men-of-war is increasing, yet at the present time, I

believe I am correct in saying, the science of Electricity is only recognised by the provision, in the largest battleships, of one or two mechanics, taking rank with a chief boatswain's mate or chief gunner's mate, and junior to the youngest naval cadet. In the great age of British seamen, naval officers were as proud of being good seamen as of being able to fight their ships, and many of our greatest victories were won as much by good seamanship as by the old bull-dog courage. The captains then knew every sail, every rope, and what could be done with them—a striking contrast even to our thoroughly practical cousins at the battle of Santiago. An Electrical Department should therefore be organised without further delay. It may be fairly asked also who supervises the work that is done for the Admiralty, and of what value is the supervision? The result of this neglect of the country's interest is apparent at every step. We have the absurd compromise in the matter of voltage, maintained long after every one else has moved on. We have open-type engines, with single cylinders, though the steam they are to consume is at from 275 to 300 lbs. pressure. We have the pathetic complaint that the stray field from the dynamos affects the compasses, and the more pathetic appeal to manufacturers to help their lordships out of the difficulty; and again we have the compromise. For some inscrutable reason the manufacturer is not allowed to attack the problem, as he would like to, by providing plenty of iron around the dynamo, by enclosing it, as motors are now enclosed for use on shore; and by making the whole machine larger if necessary, to keep the working temperature down. He is restricted as to weight, and so the problem is, as usual, half solved. Mr. Walker.

I should like to ask the author of the paper if any measurements of steam consumption have been made on the single-cylinder engines using steam at 300 lbs. pressure, and if there has not been considerable trouble with cylinder condensation. I venture to think that if tests were made, the results would be somewhat startling. Would it be too much to suggest that the Admiralty should take a leaf out of the book of any central station engineer, and try at any rate the result of running the dynamos from triple-expansion engines, enclosed? I also suggest that if the auxiliary engines were displaced by electric motors, taking their current from a central dynamo station, most of the trouble of the water coming over when the auxiliaries are started would disappear.

I think the Admiralty have been right in not allowing parallel working of the dynamos, but hardly see why it should be necessary to extinguish any particular group of lights when switching from one dynamo to another, as the same arrangement is made in some central stations without extinction. I observe that the Admiralty are keeping to the old form of switchboard, which, whatever might have been its virtues fifteen years ago, can surely be improved on now with the experience that has been gained during that period. Lead-covered vulcanised-rubber cables are probably the best that could be employed for men-of-war, provided there is plenty of rubber. In view, however, of the increased scarcity of rubber, it might be worth while to try a special form of some of the paper-covered cables. The current-density, though, should be very much lower than 1,000 amperes per square inch.

Mr. Walker. Every 100 amperes by which the current density is reduced adds considerably to the life of the insulation of the cable. I agree with the author in thinking the employment of wood battens for the support of the cables a retrograde movement; if there was one thing made clear by the actions of Santiago and The Yalu, it was the great danger of fire breaking out in action especially where any woodwork was present. It should be remembered that, when a shot or a shell strikes any part of a ship, at the moment of impact the enormous amount of energy stored in the projectile is instantly converted into heat; and that, in addition, a large portion of the energy delivered to the chamber of the gun at each explosion is also converted into heat that remains in the gun and its surroundings. Hence the temperature of the ship as a whole, and of its metallic shell in particular, must rise enormously, as was found in the actions named, leading to the ignition of anything of such a combustible nature as wood, that may happen to be in the neighbourhood. I should also join in the author's condemnation of the Admiralty joint shown in Fig. 11A, as I doubt its watertight qualities. Water has a knack of finding its way through very small spaces by capillary action, and in my experience it is most difficult, if not actually impossible, to make a joint of the nature described without leaving a capillary space. There is also a very real danger of damaging the insulation, in the process of making the joint. I would suggest that, for the junction boxes and similar arrangements, the plan that has been worked out by the British Insulated Wire Company, in which the lead covering of the cable itself is sweated to the base block, or something on the same lines, would be more satisfactory than the red-leading system. Filling in with red-lead is at best very uncertain—there is always the danger of leaving capillary spaces. I would suggest also that either concentric or twin wire might be used with advantage for the smaller conductors.

The Admiralty are quite right in using looped, in place of capped, lamps, but surely something better might have been found than the amateur arrangement that is used for connecting the cables to the lamps. Any maker's catalogue shows fittings that are at least more suitable than the makeshift arrangement in use. But why not have lamps made with special loops, strong enough to withstand the vibration during the life of the lamp, and also strong enough to stand an occasional spark without requiring replacing? Again, the watertight fitting, shown in Fig. 13, is not, in my opinion, watertight. If the slate separator and the rubber washer are not very carefully fitted, the water will find its way through; and in any case, after the apparatus has been opened once or twice, there will at least be a capillary space. Although aware of the objections to the use of accumulators on board ship, I suggest that, by proper arrangement, searchlights might be worked from accumulators, especially on board men-of-war; but the objections would probably very largely disappear if a proper electrical staff were carried, and there can be no two opinions as to the convenience of the arrangement if it could be properly carried out. The accumulators could, of course, be made use of for other apparatus, such as signalling, firing batteries, and for lighting when in harbour. The

problem of communication on board men-of-war, as the author remarks, is by no means solved, and it is a very difficult one. Completely new ground will probably have to be taken in working out the problem. The ordinary telephone apparatus and electric bell arrangements are far too delicate to stand the enormous strains to which they will be subject, when the ship is in action, or even when firing her monthly allowance of ammunition. Apparatus that is to be of any use under the conditions must be very strong, and must have ample provision for the vibration to which it will be subject. This is only to be obtained by large and comparatively heavy apparatus worked by comparatively powerful currents. The gun-firing and torpedo-firing arrangements appear to be remarkably clumsy, but with an electrical staff would very soon be simplified. Richards and Evershed's engine-room telegraphs are beautifully worked out apparatus, and the only question is whether they would stand firing over, or at. Mr. Walker.

With regard to power, although it may be some time before a ship is driven across the Atlantic by means of motors furnished with current from accumulators, that time will come, and perhaps before some of us think. It will be remembered that it was said by a leading scientist of the time, when the marine engine was first introduced, that no ship could carry sufficient coal to take her across the Atlantic. The requirements of the motor car will probably help the problem of ship propulsion very considerably. But there can hardly be any question as to the advisability of driving all the auxiliary engines by means of electricity. That is to say, of replacing the existing steam plant by electric motors. It has long been known that these auxiliary engines are terribly wasteful of steam, some of them using as much as 250 lbs. of steam per brake h.p. while in actual work; and in addition there is the enormous waste constantly going on by condensation in the pipes while the engines are standing.

The author, at the end of the paper, propounds two questions: Should the power distribution be on the continuous-current or the polyphase system? In my opinion the continuous-current would be by far the best, for the present at any rate. As the author very properly remarks, it has the advantage of simplicity, a matter of considerable importance under present conditions, in the complete absence of an electrical staff. And the matter of the commutator of the continuous-current machine is not now of the importance that it was. Even a blue-jacket could be trusted, in most cases, to look after it without any fear as to the result.

On the other question, that of voltage, I have a very novel suggestion to make, and one involving practically a revolution in dynamo and lamp practice. It is that, instead of a higher voltage being adopted, which would almost naturally follow if lamps of higher voltage can be made to stand, a *very* low voltage should be employed and the ship itself used as the conductor, not only as a return, but as lead and return. The dynamos would be connected directly to the body of the ship, and the lamps, motors, etc., would be also connected directly to the ship, the necessary difference of pressure being obtained from the position at which the two connections were made. The voltage would,

Walker. [illegible] and the currents correspondingly high, and [illegible] difficulties [illegible] overcome at every step [illegible] compasses, and with other [illegible] evident [illegible] in some experiments I have made [illegible] purpose, it could be made, the [illegible] difficult problems, that are [illegible] with work on board ship.

[illegible] disappear and with them the possibility [illegible]. The lamps would necessarily be [illegible] present available. And this [illegible] arrangements. The problem in[illegible] a very difficult one, but it is [illegible] the world has ever seen.

Mr. [illegible] Although practically a novice [illegible] that the great motive power [illegible] As Naval Architect to the Thames Ironworks [illegible] pass without saying that [illegible] design for a torpedo depôt and [illegible] Imperial Japanese Government. I suggested that [illegible] the propelling machinery [illegible] such as ventilating fans for the [illegible] parts [illegible], etc., air-compressors for the supply of [illegible] torpedoes, distilling machinery, refrigerating machinery [illegible], coal and ash hoists, and boat cranes. I also [illegible] for driving the various machines in the work-shops [illegible] planing machines, shaping machines, drilling machines, [illegible] machines, punching and shearing machines, circular saw, forge fan for forge and copper-smiths' hearth, Fletcher's patent cupola for [illegible] iron and brass, etc.; together with motors for training, elevating, and loading the guns. There was also, of course, a complete installation provided for internal lighting and searchlights, to consist of about 500 incandescent lamps of 16 C.P., head and side lights of 50 C.P., yard-arm reflectors, each containing eight 50-C.P. lamps, with the necessary signalling lanterns. The searchlights projectors were to be four in number, 24 inches in diameter, with hand and automatic lamps taking 100 amperes each. The main switch-boards for motors and for internal lighting circuits and searchlights, with all fuses, switches, ammeters, voltmeters, etc., were to be fixed near the dynamos.

With such an installation it is evident that more than ordinary attention should be given to the position and dimensions of the dynamo room, and consequently I gave an entire compartment of the ship, extending the whole breadth of the vessel just abaft the main engine rooms, and having a length of 18 feet, giving nearly 10,000 cubic feet of space. Up to the present it has been the practice to design vessels to carry their respective armaments with corresponding powers of offence and defence, with propelling power to give the requisite speed with the necessary coal spaces, and to assign some spare corner of space for the purpose of stowing the dynamos, which have been treated quite as a minor fitting; but it is evident that if all the auxiliary engines

mentioned above are to be carried and driven electrically, the dynamo compartment must have a much more important place. From the remarks made by Mr. Richards it is evident that whatever other Governments may be doing, the British Government up to the present time has not given electrical appliances the consideration that it would appear they are entitled to. Up to the present the Admiralty has no *bonâ fide* electrical engineering staff. Men who have been educated as naval constructors have taken up this branch of electrical service, and though no doubt capable officers so far as their training goes, must be wanting in that special knowledge of electrical engineering which is demanded for obtaining the best results in the Navy. As the first naval power in the world, it does not look well for this country to be watching the experiments made by other countries, and then, if successful, adopting them. It may exhibit shrewdness, but it appears exceedingly mean and paltry. Such a course would be quite excusable in the case of minor powers, but for England more enterprise is certainly needed, and I hope that Mr. Grove's paper will do something to draw attention to this very important matter. Mr. Mackrow.

Mr. C. E. GROVE, in reply: I feel greatly honoured that the paper has elicited so much criticism. Mr. Grove.

A large part of the discussion, both at the meeting and in the communicated remarks, deals with the present position of the British Admiralty in regard to electrical engineering matters, and I will, therefore, deal with that first. For my own part, I am neither able to share Mr. Evershed's satisfaction nor to go as far as Mr. Crompton in the other direction. Mr. Evershed appears to think that it is a fair subject of congratulation "that our own Navy is not so far behind the navies of the rest of the world." It seems to me a pity that it should be behind at all. If I rightly discern the matter, the desire of every patriotic Englishman is to see the British Navy in all respects well ahead of every other navy; and considering the vast resources of this country both in material wealth and engineering skill, there appears no reason why it should not be.

Mr. Crompton, I think, puts the case for the electrically controlled projector very strongly, and it does not appear to me that Mr. Richards' reply on this point is final. I am inclined to begrudge him the satisfaction he derives from the failure of such apparatus in the late American war. The American naval war took place two years ago, whereas it appears that the English Navy might at any time within the last eight or ten years have been supplied with electrically controlled projectors and have obtained experience of them at first hand. There are many forms of such apparatus, and it does not necessarily follow that because the American type of projector failed in particular circumstances that other types must need fail in other circumstances. There is a general uniformity of practice nowadays in foreign navies in regard to the adoption of automatic projectors. And it is to be remembered that if the automatic gear fail, the projector is in no worse state than an ordinary hand projector.

Mr. Richards' remarks are particularly valuable, because he indicates on many subjects what the official attitude is. I think Mr.

[illegible]

[illegible] Still more does my remark apply [illegible] whose representatives [illegible].

In regard to [illegible] power for auxiliary purposes in the Navy, Mr. Richards appears to agree that the conversion suggested would be [illegible]. The machines co-operating with the main engine that I left to be steam driven for the present were feed and condenser pumps and the like, as mentioned on page 581. Marine engineers already realise how wasteful these pumps are, and the suggestion has been more than once made that it would be economical to relegate all these pumps to a central pump-room, where they might be driven in bulk by economical engines. Were this ever to be done, I should expect that it would be but an intermediate step to replacing the steam drive by the electric drive, even for these services.

As regards reliability, I agree with the remarks that have been made, that if there is any difference between the reliability of a steam-engine and that of a dynamo or motor, the advantage is in favour of the latter; but it is extremely difficult to get engineers who are mechanical- or marine engineers without electrical experience to believe it. Everybody knows the great difficulty there has been to make people believe that tramways, for instance, could be worked satisfactorily by electricity; and even now that so much work has been done, there still exists a great deal of scepticism and prejudice. No doubt in due time, when electrical things get used more largely, every engineer will have to be an electrical engineer, and things will then stand on their proper footing.

Mr. Richards observes that upon the application of electric power to working guns the general question of the application of electrical power will be largely decided, and that as a first step it will be necessary to convince the gunnery officers that the change is beneficial. Now the British naval gunner is entitled to great respect; he is the man on whom we shall all have to rely in the hour of need, and, as a gunner, I am prepared to doff my hat to him any day, for, as a gunner, I believe he has no equal; but when he is used as a bogey, as Mr. Richards [illegible] argument, I am disposed to [illegible] electrical turret to work with, how [illegible] question? The British [illegible] subject. Yet the [illegible] the American

Navy, but in several others. The subject is large and very important, and wants attacking boldly. It is incomprehensible to me that the Admiralty should be content to wait for years to see what use other Powers make of such inventions as these, instead of conducting first-hand trials with liberality and enterprise on promising inventions. If I appear too dogmatic in criticising one Government department, I should like to illustrate my remarks from personal knowledge of the methods of another. Mr. Grove.

From 1887–1892 I was a member of the staff of the Engineer-in-Chief of the Postal Telegraphs. This was a period of great telegraphic activity, and within it the speed of Wheatstone automatic working was increased on several occasions, the multiplex system was extended both as regards the distances covered and the number of "ways" simultaneously operated, cable speeds were improved and a host of improvements made in all apparatus, from simple bell telegraphs to high-speed repeaters and telephone exchange apparatus. Each of these principal jobs was continuously watched by a highly specialised technical officer, to whom no adjustment was too minute and no detail too trivial for personal attention; and who by no means confined himself to office direction, but who controlled the practical working of the apparatus in the galleries, often for months together, until the effect of every change had been thoroughly investigated and every difficulty that might arise from ignorance or unfamiliarity on the part of the operating staff had been removed. The general result of this system is known to all in the premier position occupied by the British Postal Telegraph system. Is there any adequate reason why such a promising subject as the applications of electrical power on warships should not be similarly tended and developed by naval electricians? Such a course would at least save executive officers from the false position of condemning what they only imperfectly understand.

Mr. Swinton referred to hydraulic gun mechanism, and showed how necessary it is in moving guns to have a slow, steady action. I am an admirer of the simplicity and beauty of the hydraulic mechanism, and I suggest that the reason why hydraulic mechanism has been brought to the state of perfection it occupies for gun work, lies in the fact that our particular firm of gun-makers has long been Messrs. Armstrong, Whitworth & Co., who are also our leading hydraulic engineers. The two systems existing under the control of the same company, nothing could be more easy or more natural than to develop the two together. Thus it comes about that we have actually got, without question, a very fine system of hydraulic control. But if Messrs. Armstrong had been electrical engineers, and hydraulic apparatus came after electrical engineering instead of before it, this story might have been reversed. People who have independently attacked the subject of gun-control electrically have obtained extremely satisfactory results. I refer particularly to the Ward-Leonard system of control, which seems to lend itself perfectly to the adjustment to minute fractions of degrees of the gun-turrets, and the momentum effect in that system of control, I understand, is almost nil. Mr. Mordey tells me that the same method of control is used over and over

Mr. Grove.

again in lifts, and is quite successful where momentum effects have to be dealt with, and where quickness and smoothness of action are essential. It is to be observed, moreover, that for the present purpose it is not necessary to prove that electrical control is *better* than hydraulic control; if it is as good, the investigation need not be carried farther from the gunnery point of view; the matter is then ripe for the consideration of the naval architect, who must decide as between various dispositions of weight and space, efficiency as affecting coal consumption and bunker capacity, and so on, as mentioned in the paper. Mr. Richards rightly observed that the changes are so far-reaching as to amount to designing a warship around a central station. Is this an insuperable difficulty? Ships have been, are being, and will be, year by year, designed around various arrangements of guns and armour. And when the Belleville boiler was introduced, and it was found necessary, in consequence, to reapportion space and redistribute weights, the changes were vast enough to amount to designing ships around the Belleville boiler.

I turn now to various points of detail in the discussion. In regard to working searchlights off 200-volt mains, I regard the rotating transformer as an undesirable addition. The total capacity required on both the motor and generator sides would be about 50 kilowatts; hence the weight would be considerable. The machines could not be put on the bridges or masts where the projectors are, but would necessarily have to be in some machinery room, hence little saving of cable could be effected. For these reasons I think if the searchlights could not be worked direct or by a series-parallel arrangement as suggested, it would be better to have special dynamos and circuits for them than to employ transformers.

I agree with Mr. Richards and Mr. Noakes that alarms for the navigating lights are not indispensable. The Japanese, however, for whom those described in the paper were designed, think them important; and hence they have a place in the description of existing equipments.

I thank Mr. Swinton for the information he gives about turbines, and Mr. Wilde for his interesting historical notes. I accept the correction respecting the descriptive title of Mr. Wilde's machine. I am acquainted with the modern Sautter-Harle projector, and would have included particulars of it, and of many other things, had not the paper already exceeded the usual limits.

In reply to Mr. Allingham's questions, the lead cables are heavily painted up when in position on board, hence moisture does not get to the lead. Cables with impregnated parchment insulation have been used, but have given place to rubber. Twin cables might, perhaps, be used for the smaller sizes, but for lighting work single wires are preferred everywhere on the score of convenience. Certainly the larger sizes of cables could not be twin; they are already heavy enough with single cores.

As regards batteries, it must be remembered that the primary batteries used in the Navy are of exceedingly good quality, and although not a cheap form in themselves, are in the long run, I believe, less costly and less troublesome than accumulators, which have several

times been introduced for working apparatus, but always abandoned again. The use of the full lighting voltage for instrument working is undesirable, as there is so much power behind it that the instruments are in danger of getting burnt up if a leak is started by moisture. For some purposes small motor generators are employed to give 12 to 15 volts on the secondary. The Barr & Stroud apparatus is worked in this way. Mr. Noakes has noticed that I omitted to mention this. Mr. Grove.

Mr. S. F. Walker's communication contains several serious misconceptions, and I am afraid there is not much of value in his remarks. Mr. Walker appears to think that single-cylinder engines working at from 275 to 300 lbs. pressure are used for dynamo driving. This is not the case. The almost universal practice is to use compound engines *strong enough* to work with the full pressure if necessary, but working ordinarily with 200 lbs. steam, at which pressure the steam is supplied through reducing valves. This, I think, is a good arrangement, and more economical than triple expansion engines would be, considering the small powers developed, and the fact that the engines often have to run lightly loaded. While the older engines were of open type, enclosed engines (double-acting) are now pretty common. The steam consumption at full load with 200 lbs. steam is about 28 lbs. per E.H.P. hour, though I have seen lower amounts guaranteed.

It is imperatively necessary that cables on men-of-war must have waterproof insulation, and this is an important reason why impregnated paper cables should not be employed. Beyond this, as the paper cables would have to be worked at a lower current density, they would be larger and heavier, while the increased cost of the conductor due to working at a low density would go far to pay the difference in the cost between rubber and impregnated paper. Watertight glands in boxes and bulkheads are made as Mr. Walker suggests they should be, by sweating the lead covering of the cable to glands or plates; it is obviously impracticable to solder the cable direct to the box or bulkhead, hence, some packing below the gland is necessary, and experience proves that red lead is much less objectionable than anything else. Mr. Walker appears to think that the Admiralty use ordinary loop lamps, which is not the case. The lamps are made with special loops made of twisted platinum wire, which last very well when accurately fitted. My remarks on this point in the paper had reference to the difficulty in fitting originally.

I differ entirely from Mr. Walker's statement that "the gun-firing and torpedo-firing arrangements appear to be remarkably clumsy." As I have had no hand in designing these, I may say freely that, so far from being clumsy, I think they are exceedingly well adapted to their purpose, the torpedo-firing circuit being particularly clever, and it is not clear to me how they could be simplified.

I find some difficulty in taking seriously Mr. Walker's suggestion that dynamos of very low voltage should be connected directly with the hull of the ship, the lamps and motors being similarly connected. There are more than 1,000 points in a battleship where lamps or other things have to be connected. Is it suggested that at all places where current is required, sufficient difference of potential could be found

Mr. Grove. between points near together to secure anything like uniform and constant lighting? If, on the contrary, the assumption is that there should be anything like a steady fall of potential, say from end to end or from side to side of the ship, how would it be possible to dispense with cables, when the voltage was *very* low, and the current, and consequently the copper on that account, *very* heavy?

In conclusion, I wish to say that I am much gratified with the way my paper has been received, and trust it may be of use in advancing, to however small an extent, this branch of our profession.

The President. The PRESIDENT: Your applause shows that you approve of this paper, and that it is almost a work of supererogation to ask you formally to return your thanks to Mr. Grove. We all feel a great debt of gratitude to him.

Carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Members:

Nelson Graburn.	The Right Rev. Monsignor Gerald Molloy, D.D., D.Sc.
Walter Rutherford.	

Associate Members:

George Carrick Anderson.	William Brown.
Frederic Chalmers Armstrong.	Henry Reason.

Associates:

Peter Michael Swan Brodie.	Frank Langley.
Kenneth Findlater Campbell.	William Marsh.
George Dean.	Frederick Tolley.

Thomas Brown Wright.

Students:

Percival Francis Crinks.	Frank Heppinstall.

Alfred Sadler.

The Three Hundred and Forty-Sixth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 26th, 1900—Professor SILVANUS P. THOMPSON, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on April 5th, 1900, were read and approved.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Members—

C. J. Robertson.

From the class of Associates to that of Associate Members—

H. Wilson Bagot.
Hilton Johnson.

From the class of Students to that of Associates—

Guy D'Arcy Meynell.

Donations to the Library were announced as having been received since the last meeting from Dr. W. Reuling, Messrs. Whittaker & Co., Mr. O. V. Thomas, Member, and Mr. J. T. Morris, Associate Member; donations to the *Building Fund* were announced as having been received from Mr. P. F. Crinks, Mr. A. B. Field, and Mr. G. E. V. Thomas; and to the *Benevolent Fund* from Messrs. Pirelli & Co. (Milan), Maschinenfabrik Oerlikon, Findlay Durham and Brodie, Johnson & Matthey, James Williamson & Son, Vitrite Works, Limited, Rheinische Glasshutten Actien Gesellschaft, Bedermann & Czarnikow, A. Finnemore & Co., The Steel Conduit Company, Thomas Taylor, F. Espir, The United Electric Company (Incandescent

Lamp Department), McAlpine & Co., The British Thomson Houston Company, and A. H. Bate; to all of whom, on the motion of the President, a vote of thanks was unanimously accorded.

Messrs. E. C. Smith and E. D. Phillips were appointed scrutineers of the ballot for new members.

The PRESIDENT: In accordance with Article 45, it is my duty to read to you the list of Council nominations for election at the Annual General Meeting—the election of Council and Honorary Officers for 1900–1901:—

MEMBERS NOMINATED BY THE COUNCIL FOR OFFICE IN 1900–1901.

As President.

Nomination.	Professor J. PERRY, F.R.S.

As Vice-Presidents (4).

Remaining in Office.	W. E. LANGDON. JAMES SWINBURNE. R. KAYE GRAY.
New Nomination.	E. MASCART.

Ordinary Members of Council (15).

Remaining in Office.	Major P. CARDEW, R.E. JOHN GAVEY. ROBERT HAMMOND. A. J. LAWSON. P. V. LUKE, C.I.E. W. M. MORDEY. R. P. SELLON. A. A. CAMPBELL SWINTON.
New Nominations.	H. H. CUNYNGHAME, C.B. HENRY EDMUNDS. S. Z. de FERRANTI. HUGO HIRST. J. E. KINGSBURY. C. P. SPARKS. A. P. TROTTER.

Associate Members of Council (3).

Remaining in Office.	S. EVERSHED. R. W. WALLACE, Q.C.
New Nomination.	W. R. COOPER, M.A., B.Sc

OFFICERS NOMINATED BY COUNCIL FOR 1900–1901.

As Honorary Auditors.

For Re-Election. F. C. DANVERS. E. GARCKE.

As Honorary Treasurer.

For Re-Election. Professor W. E. AYRTON, F.R.S., Past-President.

As Honorary Solicitors.

For Re-Election. Messrs. WILSON, BRISTOWS, and CARPMAEL.

I have now much pleasure in calling upon Professor George Forbes to give us his paper.

ON DISTANT ELECTRIC POWER TRANSMISSION.

By Professor GEORGE FORBES, F.R.S., Member.

Your President did me the honour to invite me to read a paper on the subject of the distant electric transmission of power, to which I have devoted much attention during the last ten years. From the remarks he made at the time, it seemed to me that what he most desired was a description of the works of this character which have been established in different parts of the world, with the object of provoking a discussion, on their various merits and defects, by members of the Institution. I regret that to myself it seems undesirable that any one should give to the Institution descriptions of works carried out elsewhere if he has not an intimate personal practical knowledge of the works; but in view of the fact that the discussion of this paper may bring out information from those who have actually had the handling of such works, I have yielded to the President's wish to a certain extent. The first part of the paper is devoted to the description of certain selected transmission plants, each one put up by a different contractor, and each one having some special point of interest. But I must freely confess that the only one of these of which I have that intimate practical knowledge which enables one to judge on the merits or defects of a scheme is the plant at Niagara Falls, the plans for which were prepared by me in 1890 and

carried out between that date and 1895, and the actual working of which I have thoroughly investigated up to the summer of 1899, by a study of the journals, log-books, and complaints from consumers about faulty supply. Concerning the other installations, I have had to make use of the printed descriptions appearing in technical and other journals, which are always liable to mislead, especially as to the satisfactory nature of the supposed uninterrupted supply of power.

The second part of the paper deals with some of the problems that face the consulting engineer in his attempts to introduce the highest economy, especially in the transmission lines, as this is the most important part when the distances are great. To these sections of the paper some words have been added to give a general view of the methods in use by different contractors. Hitherto manufacturers and contractors in this country, having few great water powers in Great Britain, have neglected to attempt the supply of suitable machinery for other parts of the world, and run a risk of being passed over entirely in the future as they have been in the past, when tenders for the electric utilisation of water powers are asked for; it is perhaps wrong to say that they have been overlooked, and more just to say that they have refused to undertake such work. I venture to put forward the opinion that this is unwise, and I trust that the immediate progress that we expect in the transmission of power generated in the neighbourhood of coal-pits will lead the manufacturers of this country to appreciate the large field that is opened to them abroad for the utilisation of water power.

If this be done I believe that British manufacturers may work upon new and independent lines and that they will have a large outlet in our Colonies and other parts of the world; because out of numerous tenders that have been submitted to me for the transmission of power from waterfalls, none of the foreign firms who have tendered seem to me to have started on the best lines for making such a work successful and absolutely free from interruptions.

If our manufacturers, owing no doubt partly to the fact that their hands are full, have been unwilling to undertake these great works, while foreign firms have been making a splendid start, it must be allowed that the want of progress

in our Colonies is also largely due to the timidity of our financial men. It is not in this country that you would have found men with the boldness to risk their capital in transmitting and distributing electricity for power purposes, at a date (1890) when there was only one example of such transmission and distribution, viz., in a small village near the frontier of France and Switzerland. Nor would confidence have been placed by them in an electric transmission by means of alternating current at a date when there was not a single alternating-current motor in commercial use, nor in the advantages of lower frequency than any which had been thought of up to that date (1893), when nine-tenths of the members of this Institution who rose to discuss the question condemned a frequency of 25 periods per second as impossible and extravagant.[1] Our capitalists are too apt to say that such things are too experimental, when any step is taken to improve methods. Yet the capitalists in America who undertook to utilise the Niagara Falls did all these things, made a commercial and engineering success of their works and have been imitated in their methods all over the world.[2]

Attention must now be drawn to a few of the most interesting cases of using electricity for developing the power of waterfalls.

I. Of the various plants for transmitting electrical power from waterfalls, one which derives its chief interest from the greater distance to which the energy is transported, is in South California at San Bernandino and Los Angeles, carried out by the General Electric Company, U.S.A.

The water is taken from the streams in the San Bernandino Mountains, and it is carried in canals and tunnels for about two and a quarter miles. It develops power under the head of over 700 feet, three-phase electric currents are there generated and raised by transformers to a pressure of 33,000 volts, and the current is transmitted over a distance of 80 miles to Los Angeles; 80 per cent. of the water conduit is in tunnel, and of the rest part is open masonry canal and

[1] The unqualified success of low frequency at Niagara Falls has now, ...wever, converted even former opponents, and this Institution passed a ...mmendation last year that a frequency of 25 should be a standard for ...r transmission.

[2] ...he only financial group who ever in this country showed such boldness ...c matters was the band of men who realised that Ferranti's brilliant ...e right, and who started the London Electric Supply Company.

the remainder timber flumes. There are 18 tunnels whose total length is 11,555 feet, the longest being 2,074 feet. There are 2,662 feet of wooden flumes, 167 feet of open masonry canal, 121 feet for a sand-box, and 57 feet of reservoir and forebay at the head of the penstock. The water is taken from a point 3,422 feet above sea-level, the power-house being at a level of 2,670 feet; the slope of the canal is 9·5 feet per mile, leaving an available head of 728 feet at the power-house. The streams used are the Santa Anna River and the Bear Creek.

The best description of the Civil Engineering Works is given in the *Engineering News*, New York, March 9, 1899:— Pelton wheels are used with a nozzle 3¾ inches in diameter, the wheels are 82 inches in diameter, the regulation is obtained by deflecting the nozzle from its most effective position as the load falls off; four such wheels and generators are in place; the generators deliver current in three phases, and the revolving wheels carry 20 poles, the armature being external, each generator delivers 1,000 horse-power, running at 300 revolutions and giving 750 volts. There are twelve transformers in banks of three, on foundations of steel beams and concrete, 30 inches above the floor for the purpose of cooling by a forced air draught. Each transformer raises the pressure to 19,000 volts, making 33,000 volts between wires on the 3-phase circuit, the Star connection being used; ⅜ths of an ounce pressure is used with blowers 280 inches diameter, each requiring three horse-power. There are two 3-wire circuits of No. 1 (B. and S.) copper wire, and the insulators are placed on the posts at the angles of an equilateral triangle. These insulators, over 6-inch diameter, are bell-shaped, of glazed porcelain, and are bolted to the cross-arm. There are 44 posts to the mile of white cedar, from 35 to 65 feet high, with 8-inch tops. At Pesadena the voltage is reduced by oil-cooled transformers to 2,200 volts, and the current is used to work a synchronous motor which drives a direct-current generator of 525 kilowatts. At Los Angeles there are six 250-kilowatt transformers reducing the electric pressure to 2,200 volts, and four sychronous motors which drive generators for lighting with continuous current. The information which would be most useful as to the results of working this plant would be about the continuity of

working and freedom from interruptions. Such information cannot be obtained accurately except by a prolonged stay at the spot, examination of journals, etc. I am unable to assist in this.

II. The Snoqualmie Falls have been developed for transmitting power to Seattle and Tacoma, by the Westinghouse Company, U.S.A. The features of greatest interest in this case are the use of the high electric pressure of 30,000 volts, and the use of aluminium for the conductor on the long transmission line. It is impossible for any one to know what success has attended these novelties, unless he were to examine not only the plant but the log-book and correspondence. Continuity of performance is of primary importance, but we cannot tell from published accounts whether this has been attained in the present plant with 30,000 volts. Also we have not any means of knowing what success has attended the use of aluminium wire.

In the development of the Snoqualmie Falls a vertical shaft has been dug 260 feet deep, 10 feet by 25 feet, and the tailrace tunnel is 200 feet. A 7 feet 6 inch steel penstock is in place, and there is room for another. The underground chamber for machinery is 200 feet long, 40 feet wide, and 30 feet high. The penstock is connected at the bottom to a steel receiver 10 feet diameter, 1 inch thick, and 80 feet long horizontally, besides 60 feet length of pipe 7 feet 6 inches diameter.

There are four 1,500-kilowatt 3-phase alternators at a frequency of 45 cycles, and at 1,000 volts. The armature rotates, and is 8 feet diameter, and weighs over 10 tons. Laminated poles are cast into the field frames.

Transformers of 500 kilowatts with oil insulation are used. Mesh connection (or Δ) for the three phases is used both in primary and secondary.

As to the high-pressure transmission line of 30 miles, it is said that 33 tons of aluminium are used for going to Seattle and 34 tons for going to Tacoma, and that each route has two separate 3-phase circuits with 30 inches between wires, that the average span to Seattle is 110 feet and to Tacoma 150 feet, that Nos. 1 and 2 B. and S. gauge and McIntyre joints are used. There is some discrepancy

between the weights of wire used and the power that is said to be transmitted.

The whole of the information here given is taken from technical journals. On this line the electric pressure has sometimes been raised to 40,000 volts, when the phenomena of brush discharge acquire considerable importance. This led Mr Scott, of Pittsburg, to his interesting experiments on this subject, published by the American Institute of Electrical Engineers.

III. The Paderna development of the Adda River for supplying electric energy to supplement that in use at Milan, a distance of 33 kilometres, derives its chief special interest electrically from the fact that the energy is generated direct in the alternator at the comparatively high electric pressure of 13,500 volts, the plant having been designed and constructed by Messrs. Brown, Boveri & Co. The only other plant in the world which can be compared in this feature with Paderna is the transmission by the General Electric Company, U.S.A., from Mechanicsville to Schenectady, where both generator and motor are used at 10,000 volts without the intervention of any transformer.

It would be interesting to discuss the hydraulic part of the work at Paderna, but it is advisable under present conditions to confine remarks as far as possible to some of the electric details. Under the former head it may be said that the minimum flow of the river is taken at 45 tons per second. The dam is 150 metres long. The canal has a slope of 2 per cent., giving a velocity of 2·70 metres a second when the flow is the maximum allowed for. There are three tunnels, whose total length is 1,686 metres. The open canal is 582 metres. The total fall varies from 28·82 metres to 24·92 metres. The total head available is constantly 22·85 metres, and the suction varies from 6 metres to 2 metres, giving a total power of 13,000 B.H.P. The type of turbines is horizontal axis, double turbine to balance pressures, radial intake and axial outlet. Each double turbine developes 2,160 B.H.P. at 180 revolutions per minute. A safety valve is provided, but is not required, as it was found, when closing the outlet of a fully loaded turbine in two seconds, that the pressure rose only 9 or 10 metres without using the valve.

The dynamos are of the well-known Brown construction. Each is of 2,160 H.P. at 180 revolutions, and developes three-phase currents. The armature is fixed and external to the revolving field, which carries 28 poles of steel with laminated horns. The poles are wound with copper strip edge-on. The diameter of the revolving field is 4·1 metres, and that of the whole machine is 5·14 metres. The exciter is in line with the alternator. The frequency is 42 cycles per second. The normal pressure is 13,500 volts at the terminals, and the current should be 64·5 amperes per phase with an induction factor of 1, or 79 amperes with 37° of lag. The efficiency in the former case is 95·1 per cent., in the latter 93·4 per cent. The maximum rise of temperature is 28° C. The machines were deliberately tested at 20,000 to 21,000 volts, and it is said that accidentally they were caused to generate current at 30,000 volts without injury.

The line consists of three independent three-wire circuits on two lines of posts two metres apart, the distance between any two wires of one circuit being 0·6 metre. The mean distance between the posts of one line is 60 metres. The distance of the high-tension transmission is 32,500 metres. The wires are of copper, 9 mm. in diameter, the ohmic loss is 8·1 per cent. and the total loss is 11·7 per cent. for a lag of 37°. A lag of 45° has been observed with a line on short circuit. Wurtz lightning-arresters are used at both ends of the line on two of the circuits, and Siemens and Halske horns on the other.

At Milan the pressure is reduced by Ganz transformers of 350 kilowatts, and transmission gives place to distribution.

The above statements of facts are on the authority of E. Vannotti, and were published by Le Génie Civil, Paris.

IV. The Rheinfelden plant is here mentioned to allow of discussion on it, and because it is the most successful development of a low fall on the general lines of the Niagara undertaking. It resembles Niagara in using a vertical shaft for each turbine and dynamo. It differs from Niagara in having four different types of dynamos, some giving continuous, and others alternating, current. The turbines are by Escher Wyss, the dynamos by Oerlikon

and the Allgemeine Elektricitäts Gesellschaft. The hydraulic works are a model of good work, which I constantly kept before me when planning the work to be undertaken on the Nile Cataracts for the Egyptian Government.

If I were attempting here to give full descriptions, I would devote much space to this excellent installation. Many members of this Institution have, however, inspected the plant, and every engineer who wishes to master this branch of our profession is obliged to read the most admirable description published at Berlin (*Die Kraftübertragungs-Werke Rheinfelden*).

V. In a paper dealing with transmission schemes which have been carried out, the Genoa continuous-current plant deserves great attention. Here water power is available. The turbines are connected by insulating Raffard couplings to insulated dynamos, which are electrically connected in series. Thus 6,000 to 8,000 volts are delivered at Genoa to work insulated motors, also put in series so as to attain this high electric pressure. In a scheme purely for transmission, and not for distribution, this method of using continuous currents has a great deal of merit, and I believe that we shall all agree that we owe a debt of gratitude to M. Thury for the way in which he has worked out the method at Genoa and elsewhere. A full account of this work has been published, and deserves the closest attention. I could mention cases which have come under my own notice where this system with continuous currents would give better results than the Niagara system with alternating currents.

VI. Having satisfied your President's wish and put forward as a basis of discussion some of the plants in different parts of the world with the actual working of which I have no practical experience, it is a pleasure now to turn to the work of the Niagara Falls Power Company, concerning the working of which I may be able to supply useful information.

I do not propose here to give a full account of the machinery which we have made use of. It has been well described in the American Electrician for January, 1900. It will be better to pass lightly over this part, and devote

more attention to the lessons to be learnt from the five years of working.

This plant derives its chief interest from the following facts:—1. It was the first place except Oyonnax where a scheme was started on for generating electricity at a waterfall, transmitting it to a distance, and distributing it to consumers for power. 2. It was and is the largest project of the kind. 3. It was the first case of using the alternating current for power commercially. 4. It was the first case in practice where the commutator for continuous currents was placed at the distant end of the transmission line. 5. It was the first plant to adopt low frequency. 6. All the generators are of the same size and pattern. 7. The Niagara system in its general features has been adopted in almost every subsequent electrical development of water power. The principal feature of the dynamos is that the shaft is vertical and that the revolving field has its poles external to the armature. In the original drawings and specification issued to manufacturers a circulation of fluid for cooling the armature was provided; the poles were wound with copper strip and mica insulation, and not with wire; and there were no bolts on the outside ring to create undue air-friction. I allowed the first three dynamos to be built without these features, but the last seven have had them reintroduced.

The transformers at the power-house are the first ever made of great size, and also the first made with great attention paid to cooling by air-blast or oil. Those by the General Electric Company are 1,250 H.P. Those by the Westinghouse Company are 2,500 H.P.

For the factories within half a mile a subway is used, which I built of concrete.

For the new Carbide works a "Camp" conduit, like our "Doulton" conduit, is used with 10,000 volts.

For the Buffalo transmission bare overhead wire cables are used.

The Aluminium Company had great trouble at first with the rotary transformers used for commutating the current. These were, I believe, the first machines of this class ever ordered for commercial use. The Mathiessen Alkali Works have eleven such machines, with one induction motor for *starting the middle one.* The others are started from this

by temporary belts. They have no hunting, no sparking, and no grooves on the commutators. Hunting is prevented by a modification of the Leblanc cage on the poles. Each machine has six poles, and sparking is prevented by connecting together metallically all the commutator-bars which are in the same phase. To prevent grooving of commutators the shaft is free to move axially, and motion is given to it by an electro-magnet and spring, the current for the electro-magnet being periodically interrupted by clockwork mechanism on the wall.

The Carborundum Company's plant is chiefly interesting for the adjustable transformers, which allow very large variations in the volts and current. These have often been described in technical journals. This service could not have been given had we adopted three-phase alternators, and the rotary transformers would not have succeeded but for our low frequency.

In the new works of the Carbide Company, ten Wagner transformers, each of 2,000 H.P., were being put in when I was last there. This plant is interesting from the fact that the serious short circuits frequently occurring in the electric furnace can be satisfactorily dealt with.

Passing over other matters concerning which a volume might be written, it will be well to say a few words about the transmission line to Buffalo.

The chief peculiarity of the Buffalo transmission line is that three-phase currents are used, though generated in two phases. I very much preferred alternators of two phases as being more easily tested and attended to, and as giving a more useful machine. For the transmission to Buffalo I had no great preference for one over the other, but I found that we should be better served by yielding to the wishes of the contractors and putting in Mr. Scott's ingenious arrangement for changing from two-phase to three-phase. Fig. 1 shows the connections.

There were six bare cables on one cross-arm of the posts all the way from Niagara to Buffalo, but this arrangement is to be altered.

From Niagara to Terminal House, Buffalo, is 25 miles.
„ Terminal House to Railway House is 2 „
„ „ „ Lighting „ 4 „
„ „ „ 3 Substations $4\frac{1}{2}$ „

The full-load inductive E.M.F. is 15 per cent. of the whole. At some stations the current leads the E.M.F. instead of lagging. The Buffalo cables are three insulated lead-covered cables in a pipe, and the capacity of each is 0·55 microfarads per mile from copper to lead. The conductors on the transmission line are 0·6 inch diameter, 18 inches apart half the way, 36 inches the rest. The posts

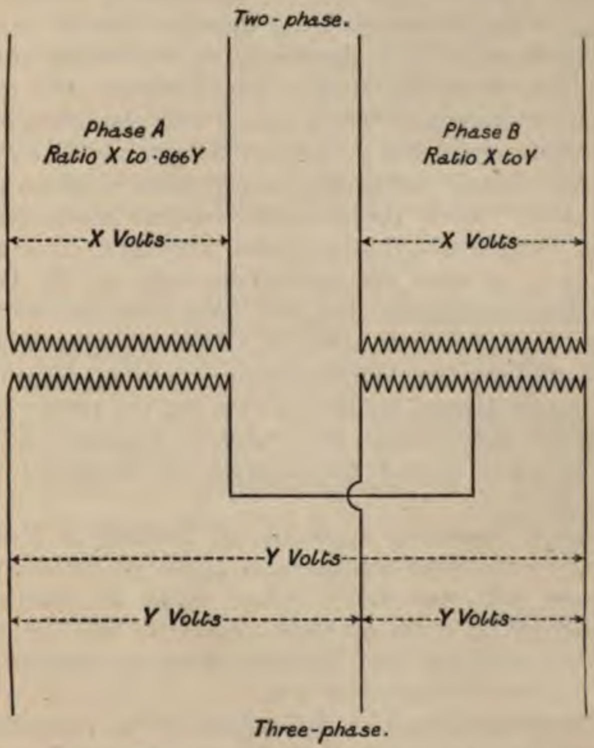


FIG. 1.—Sketch showing transformation from two phases to three phases.

are 75 feet apart. The top cross-arms are 30 feet above ground. The posts are 8 inches diameter at the top. They are not strong enough for the weight and are bent badly.

Originally a barbed wire ran the whole distance over the conducting wires. After the snowstorm of December 4th, 1898, it was removed. It was grounded at every second post.

Having looked carefully into the cause of every inter-

ruption of electric supply that has occurred in four years, I have to say that not a single electrical trouble has occurred that might not be prevented in any similar plant laid down in future.

In this brief reference to the work at Niagara Falls many features of considerable importance must be omitted; but I should like to draw attention to the ingenious automatic cut-outs with the introduction of which I had nothing to do, and which I am therefore free to praise, as they have been of the highest value in preventing interruptions of supply on the Buffalo transmission. The electro-magnetic arrangement, which comes into play when excessive current passes due to a short circuit, merely serves to start some clock mechanism which after a short period cuts out the line if the excessive current is still passing. On the Buffalo distribution these automatic cut-outs are set so as to act after one or two seconds; at the Buffalo end of the transmission line after three seconds, and at the Niagara end after four seconds. Thus a short-circuit in Buffalo cuts out the distributing lines, and no others. At the Terminal House, Buffalo, it cuts out the supply mains, but not the transmission line; and at Niagara if a short-circuit lasts four seconds the supply to the transmission line is cut out.

Another ingenious appliance at Buffalo is a motor supplied by the three transmission cables so balanced that the motor will not move except when the balance is destroyed by an earth or short circuit on the line, when its motion removes the defective line, or switches the whole load on to the other line.

There is a practical matter regarding the regulation of the turbines which deserves notice. At the period of my last inspection Buffalo was supplied by two dynamos. Now the first three turbines put down were regulated by a purely mechanical governor; the later ones by a more sensitive electrical governor. It is found in practice that the supply at Buffalo is most steady when the two turbines driving the dynamos are regulated, one by a sensitive, and the other by a coarser governor.

In conclusion of these remarks about the Niagara-Buffalo transmission it may be interesting to mention a few of the causes of interruption of the current. Some

of the Italian workmen stole copper-wire. They were put in prison. Whereupon their relatives short-circuited the wires. Boys threw chains over the transmission wires to watch the sparks, until the detectives caught them. Short-circuits or earths have also been caused by fumes and carbon-dust deposited on snow on the insulators, by fourth of July rockets, by sleet, by lightning, by careless workmen, by rats. Interruptions have occurred by overload on rotary transformers, by attendants using switches wrongly, by lightning arresters, by bad switches on consumers' premises, by accidental fire, by ice-blocks on the canal headrace. Insulators are a temptation to the owners of revolvers, but this trouble has not existed at Niagara so much as in Switzerland. These are only extracts from the nearly complete list which I made out from four years' working.

I now turn to the second portion of this paper dealing with some of the problems which I suppose have been threshed out independently by each one who has had to carry out any large transmission scheme. I wish to draw attention to Lord Kelvin's law of economy, to the use of boosters and phase rectifiers, to the relative merits of different kinds of polyphase systems, to overhead and underground conductors, and to the use of aluminium.

KELVIN'S LAW.

I should like to see an accurate volume published on the correct use and development of Kelvin's law of economy. Here I must condense. The data on which we choose our current density by this law depends on :—(1) price of copper, (2) price per annum of the H.P., (3) interest on price of copper. I desire to draw attention to the meaning of (2) and (3). When using water power which is unlimited compared with the demand, (2) is the price per annum of generating the power. When the water power is limited and the demand unlimited, (2) is the selling price of the power. If the copper be mortgaged, (3) is the interest paid on the mortgage, say 4 per cent. If the copper is paid for out of capital, (3) is the interest to be paid in dividends on the capital, say 15 per cent. I do not think that attention has been explicitly directed before to these points.

Boosters.

Lord Kelvin's law as he announced it was only true if the electric power measured at each end of the line was approximately the same; in other words, if the percentage drop in volts was small. Ayrton and Perry showed that Lord Kelvin, through neglect to notice this, was led to deduce wrong conclusions as to the economical current density to transmit power from Niagara to New York.

But by using boosters along the line the drop in volts can be corrected. Take as example an ordinary transmission line of forty miles, in which the ohmic loss in power and volts is 40 per cent. Divide the line into four sections of ten miles with a loss of 10 per cent. in each. Now place alongside of it a booster line. At the ten-mile station increase the volts to the original amount by a booster at the expense of 10 per cent. of current. In the second section there is only 90 per cent. of the current, so if the conductor is the same sectional area throughout, the second section of the booster line may be eleven miles before losing the same as any section of the non-booster or ordinary line. The third section will have a length of $1·1 \times 1·1 \times 10$ miles $= 12·1$ miles; the fourth has a length of 13·31 miles. Thus on the booster line the total loss of 40 per cent. is reached only after traversing a distance of

$$10 + 11 + 12·1 + 13·31 = 46·41,$$

instead of forty miles without boosters, and with the same sized wire. If instead of keeping the wire of constant section in the booster line we had kept the length of sections each of ten miles, and had kept the current density constant, the sectional area of the conductor in the four sections would have been in the ratios 1·0, 0·9, 0·81, 0·729, whose sum is 3·439. The weight of copper on the booster system would be thus reduced in the ratio 3·439 : 4, while the efficiency would be 65·61 per cent. instead of only 60 per cent. without boosters; or, to put it in another way, the same loss at forty miles would be obtained on the booster line with a reduction in weight of copper in the ratio of $34·4^2 : 40^2$, which requires only 74 per cent. of the copper. In this example the loss in the booster has been neglected for simplicity of description, but would be taken

account of in practice. If the efficiency of the alternating current booster is 98 per cent. on $\frac{1}{10}$th of the power, the total loss in the booster is $\frac{1}{50} \times \frac{1}{10} = \frac{1}{500}$ of the power, which may well be neglected in a general statement of results. The effects of capacity and self-induction (if alternating currents be used) have also been omitted in this description, and if not nullified the usual corrections must be made.

Table I. gives the weight of copper per horse-power and kilowatt delivered at the receiving end of a transmission line one hundred miles long with 10,000 volts at the generating end, without boosters, *i.e.*, in one section. Tables II., III., and IV. give the results with boosters when the line is divided into two, three, and four sections respectively. Corrections must be made for capacity, self-induction, temperature, and sag.

Another way of working the booster system is to add to the distance already covered a new section of the same length as previous ones, with the current density calculated by Lord Kelvin's law. In this case the cost of power must include the cost of copper up to the commencement of the new section.

We may start with one section and with power costing nothing. In this case Kelvin's law gives the economical inefficiency = 2 (see my paper before the Society of Arts, November, 1898). The weight of copper for this section per kilowatt delivered $= 4 \times 1571 \left(\frac{\text{Miles}}{\text{Volts}}\right)^2$ In any other section, the n^{th}, let

e_n be inefficiency of that section.

$1571 \left(\frac{\text{Miles}}{\text{Volts}}\right)^2 c_n$ be weight of copper for „

E_n be accumulated inefficiency of n sections.

$1571 \left(\frac{\text{Miles}}{\text{Volts}}\right)^2 C_n$ be accumulated weight of copper,

(In Table VI. I call c_n and C_n the copper factor.)

$$\text{Then, } e_n = 1 + \frac{1}{\sqrt{c_{n-1}} + 1}; \; c_n = \frac{e_n^2}{e_n - 1}$$

$$E_n = e_1 \cdot e_2 \ldots e_n; \; C_n = e_n C_{n-1} + c_n.$$

Table VI. gives the values of these quantities for 24

sections of equal length, uncorrected for capacity and self-induction.

If now we wish to use this table for other cases where the cost of power is C_n which corresponds in Table VI. to an inefficiency E_r; then the economical inefficiency say for 8 sections is $\frac{E_{r+8}}{E_r}$, and the economical weight of copper per kilowatt delivered is $1571 \left(\frac{\text{Miles}}{\text{Volts}}\right)^2. \quad (C_{r+8} - C_r)$. In this way Table V. has been computed.

Tables I. to VI. embody some of the best results of my

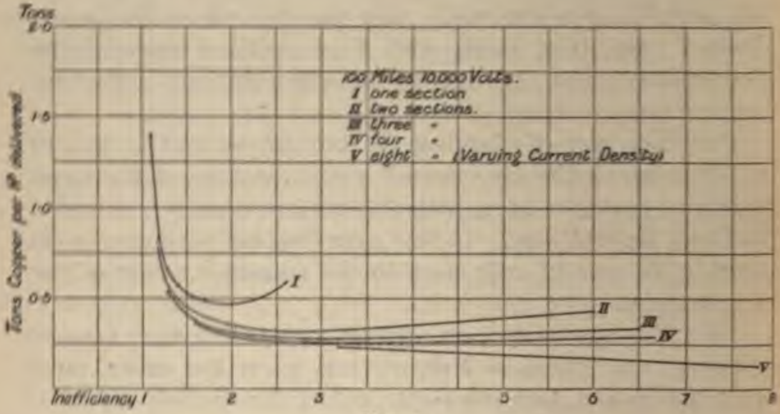


FIG. 2.

study of the booster method from the year 1894 up to to-day. The curves on Fig. 2 show the tons of copper required for each horse-power delivered at different inefficiencies. It will be seen from them that by the booster method I am able to reduce the weight of copper (by putting in more turbines and dynamos) in some cases to less than one half of what was possible by the old system.

The chief advantage of using boosters is to save copper at the cost of power generated where the latter is cheap and the distance very great. In a paper before the Society of Arts in November, 1898, it was shown that in the ordinary method of working there is no saving of copper when the efficiency is below 50 per cent. But if we wish it we can save copper still farther by making the efficiency still lower, and using the method now indicated.

Fig. 3 explains the action of boosters (1) for single or two phase, (2) for continuous current, (3) for three phase. I believe that Mr. Gisbert Kapp was the first to construct an alternating-current booster as here shown.

Mr. Scott, of Pittsburg, is the only person I know of who has published anything bearing on this; but his published statements are arithmetically erroneous, and so misleading, and he does not appear to have noticed the

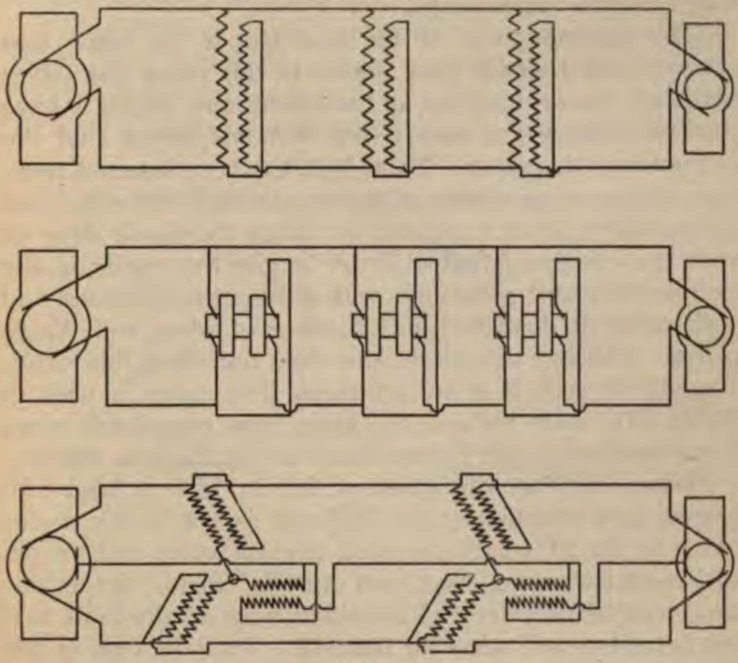


FIG. 3.

possibility of being able to save copper by reducing the efficiency below 50 per cent.

INDUCTION FACTORS AND PHASE RECTIFIERS.

The low power factor of induction motors, which lies commonly between 0·6 and 0·8, must be carefully taken into account when designing any power scheme where these are used. Synchronising motors can be adjusted so as to be without either lag or lead. But they have not been so

largely adopted as they might have been but for the necessity of this adjustment. The Oerlikon Company have used synchronous motors, doing no work, in parallel with the inductive load to furnish what has been called the wattless current. In this case the synchronous motor is excited so as to act as a condenser, and is placed at the receiving end of the line. There are other methods by which idle synchronous motors may be used to overcome self-induction, and this becomes an important matter in long-distance transmission.

The self-induction of the line has to be taken into account, and I would have added to this paper the tables necessary for working out all the effects, and which I have used for many years, were it not that this would alter the character of the paper. Table VII. has been inserted, however, to give some notion of the magnitude of the effect, and it shows at a glance the factor by which the ohmic drop of volts must be multiplied in order to give the true drop due to induction and resistance, with different frequencies, and with different diameters and distance of wires, with single phase. Distance of transmission does not affect this factor. I ought to state that an American wire gauge is used in Table VII. only because the table was completed when I was working in the United States on the Niagara scheme.

When dealing with parts of the world free from telegraphs and telephones, the beginner is apt to lay undue stress on the advantages of using an earth return with single- or two-phase transmission, and overhead wires. So soon as he calculates the effects of induction he generally finds that the benefit is not what he thought. Take the case of the Niagara-Buffalo line, with cables 0·6 inch diameter and 30 feet above ground, and using a frequency of 25 cycles per second. The impedance is the same as with similar cables (go and return) 60 feet apart and the factor is prohibitive.

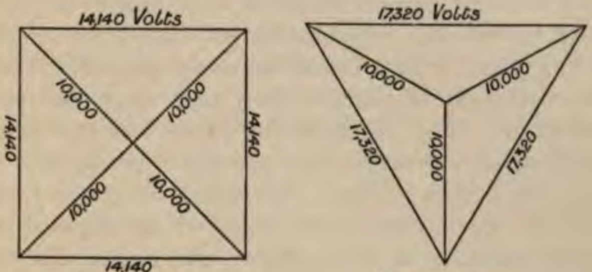
Choice of Polyphase Systems.

In choosing a polyphase system we may use two-phase, or three-phase star, or three-phase mesh. Three-phase star cannot well be used if any consumer's plant uses only one-phase, as was proved from actual trials in a paper I read

before this Institution in 1893. For these cases two-phase or three-phase mesh must be used. Three-phase mesh subjects the transformers to 1·7 times the electric pressure experienced by three-phase star, or two-phase, each earthed at the centre of the electric system.

The principal advantage of the two-phase is that the two circuits may be electrically disconnected, either always or else during tests. This facilitates the detection of troubles and gives far greater security, as I have convinced myself beyond doubt in actual practice.

It has been generally assumed that, using the same electric pressure, the three-phase system uses only $\frac{3}{4}$ of the copper required for the two-phase. This is founded purely on the convention adopted in defining the electric pressure—



Two phases. Three phases.

Fig. 4.

In Fig. 4 a three-phase star and a two-phase system are represented, each with 10,000 volts between any one wire and the middle of the electric system, which may be conveniently earthed; and the two systems represented require the same weight of copper to give the same effect (though not the same number of insulators). The volts between neighbouring wires in these cases are 17,320 with the three-phase, and 14,124 with the two-phase; yet the convention is to speak of these cases as being 17,320 with three-phase, and 20,000 with two-phase. This might be an unobjectionable convention if the trouble arising from high electric pressure was due to risks of sparks passing from wire to wire. I doubt if any one, with practical experience of the troubles that do arise, could support this view. Nine-tenths of the troubles come either from accidental or malicious short circuits, or

or from leakage of the conductors to earth. The former cannot produce a breakdown in any case. Hence leakage to earth is the only factor to be considered in this connection, and in the cases shown in Fig. 2 the security, as measured by electric pressure on insulation, and the weight of copper are the same for three-phase and for two-phase.

Overhead and Underground Conductors.

The choice between bare overhead conductors and insulated cables underground has generally to be decided upon considerations other than economy or effectiveness. In this country insulated cables will generally be employed. In this case self-induction of the line, which we know how to compensate in any case, can be got rid of. But the effects of capacity, which are more troublesome to deal with, are much increased. The electric pressure to be selected on an underground transmission depends almost entirely on the financial side of the question regarding relative costs for insulation. The Rheinfelden plant was the first case where the electric pressure was selected solely with a desire to obtain the best economy. In almost all other cases the pressure has been chosen by rules which depend on the timidity or rashness of the engineer, and occasionally on his past experience. We have not yet reached such pressures as require account to be taken of electric air-convection or brush discharge from surfaces of small radius of curvature, except for temporary experiments.

Aluminium Conductors.

A few words must be said about the use of aluminium as a conductor. The weight of aluminium required is almost exactly one half of the copper which would produce the same effect. The diameter of cable is 28 per cent. in excess of one made of copper, and the cost of insulation for an underground cable is increased in about the same proportion when we pass from copper to aluminium.

Aluminium is not a pleasant metal to deal with, but its high conductivity will make it invaluable for overhead transmission. It is true also that the weight to be supported on posts is half of copper, but the surface exposed to the

wind is greater and its strength is not great. The chief drawback to its use, especially overhead, is its liability to become rotten. This defect does not exist if the metal be pure and especially if free from sodium. But exposure to the atmosphere, especially near the sea, induces deterioration. The fact that aluminium is easily oxidised ought not to condemn it. The same is true of iron and steel, and yet we do not hesitate to place structures of these metals in exposed positions. Only we paint them; so I propose that we paint or varnish our aluminium conductors wherever necessary. We have had little experience in this direction. I laid out a few hundred yards of ¼-inch aluminium wire on a Scotch estate a year ago, and am watching the effects of weather.

Having now dealt almost entirely with the work of foreign manufacturers, I should like to suggest that a British type of power transmission might be worked out differing in some details from what is becoming the normal arrangement. But it would be an impertinence on my part to appear to suggest to manufacturers how best to look after their own interests. The reason why I venture to broach this question is that I observe in the many tenders that come under my notice for power transmission a tendency to crystallise the proposals and to settle into grooves which do not seem always to be the best. This stereotyped character has lately forced itself on my attention in connection with the proposed Mysore development of water power, and electric transmission over 90 miles. I received five tenders from the firms most experienced in this work in Europe and America. The most remarkable feature was their great resemblance to one another except in certain details. They all used 3-phase alternating currents generated at an electric pressure between 2,000 and 3,000 volts. The units varied from 1,000 to 1,333 H.P. Three used mesh connections, and two used star connections. The frequency varied from 25 to 40. All used separate turbines for exciters. All had turbines and dynamos on the same horizontal shaft. The electric pressure used for transmission varied from 23,800 to 30,000 volts. Three preferred oil cooling for transformers, one air-blast, and one natural ventilation. The line construction varied *considerably*, so did the working of the *distant transformer station*. It is not desirable to go further

[illegible]

[illegible]

I would suggest as subjects worthy of your consideration the following points:—

1. The arrangement which suits a transmission in which is also a distribution of power does not necessarily yield the best results for a plant transmitting the whole power to a long distance.

2. The high-pressure continuous-current system is very suitable for certain cases, as worked out at Genoa.

3. The two-phase alternating current is to be preferred over the three-phase in many cases, and especially where no earth return can be used.

4. The horizontal shaft for turbine and dynamo which is so much in vogue, might well be replaced by a vertical shaft, as at Niagara, Rheinfelden, and other places.

I should like to mention other matters, but do not consider the time opportune. Some, no doubt, will be spoken of during the discussion, and any remarks from others who have had experience of these matters will be of value. Most of what has been said in this paper has reference primarily to cases where water power is used, and generally to countries where bare overhead conductors are permitted. But generally the same considerations have a bearing upon cases where the power is generated by steam and where the cables are underground, although the distinctive characters of the two cases are very marked. With insulated cables the cost of insulation takes away from the superiority of two- over three-phases except perhaps when a common return is used. The same cause acts against the use of aluminium in place of copper underground. Again, in cases of generating power at the coal-pits, the transmission line generally becomes also a distribution line and militates against the use of known methods for increasing the power factor. But the most important difference between an

underground and an overhead transmission must be noticed, viz., that induction in one case, and capacity in the other, is the trouble that demands the most careful attention.

It has been my desire in this paper to disclaim all idea of teaching the members of this Institution anything about their profession. This is not a class-room. The object of this paper is only to put down a few of the ideas about electric transmission that have occurred to me in practice during the last ten years, and which seem to be the most important at this date to draw attention to, and to ask other men of experience in this work to tell us some of the results that they have obtained.

[illegible]	[illegible]	·64551	·48155
[illegible]	·578	·64409	·48049
1·74	·575	·64276	·47950
1·75	·571	·64149	·47855
1·76	·568	·64031	·47767
1·77	·565	·63910	·47684
1·78	·562	·638148	·476059
1·79	·559	·637170	·475320
1·80	·556	·636255	·474646
1·81	·552	·635401	·474009
1·83	·546	·633870	·472867
1·85	·541	·632559	·471880
1·87	·538	·631452	·471063
1·89	·530	·630536	·470380
1·91	·524	·629708	·469820
1·93	·518	·629228	·469404
1·95	·513	·628813	·469094
1·97	·508	·628544	·468884
1·99	·503	·628410	·468708
2·00	·500	·628400	[illegible]

TABLE II.

100 MILES; 10,000 VOLTS. TWO SECTIONS.

Efficiency.	Inefficiency.	Tons Copper per H.P. delivered.
·017	59·17	2·27
·12	8·27	·504
·32	3·13	·333
·61	1·63	·395
·92	1·09	1·451

TABLE III.

100 MILES; 10,000 VOLTS. THREE SECTIONS.

Efficiency.	Inefficiency.	Total Copper per H.P. delivered.
·07	13·5	·488
·09	11·0	·435
·11	9·2	·393
·13	7·7	·361
·15	6·5	·335
·18	5·5	·315
·21	4·8	·300
·24	4·1	·290
·28	3·6	·283
·32	3·2	·280
·36	2·8	·280
·40	2·5	·285
·45	2·2	·295
·51	2·0	·311
·56	1·8	·336
·62	1·6	·375
·69	1·5	·437
·76	1·3	·545
·84	1·2	·766
	1·1	1·441

[redacted]

TABLE IV.

100 MILES; 10,000 VOLTS. FOUR SECTIONS.

Efficiency.	Inefficiency.	Tons Copper per H.P. delivered.
·10	9·8	·344
·21	4·8	·267
·38	2·7	·260
·63	1·6	·365
·92	1·1	1·435

TABLE V.

100 MILES; 10,000 VOLTS.

EIGHT SECTIONS OF DIFFERENT CURRENT-DENSITIES.

Efficiency.	Inefficiency.	Tons Copper per H.P. delivered.
·53	1·9	·396
·50	2·0	·348
·45	2·2	·330
·42	2·4	·303
·37	2·7	·273
·31	3·2	·241
·23	4·3	·207
·13	7·8	·141

TABLE VI.

Section.	Efficiency of Section.	e_n Inefficiency of Section.	c_n Copper Factor for Section.	E_n Accumulated Inefficiency.	C_n Accumulated Copper Factor.
1	·5000	2·0000	4·0000	2·000	4·000
2	·6909	1·4472	4·6832	2·894	10·472
3	·7721	1·2952	5·6820	3·749	19·245
4	·8181	1·2223	6·7223	4·582	30·245
5	·8482	1·1789	7·7687	5·402	43·425
6	·8696	1·1500	8·8147	6·212	58·754
7	·8854	1·1294	9·8601	7·016	76·217
8	·8978	1·1138	10·901	7·815	95·792
9	·9078	1·1016	11·939	8·608	117·463
10	·9158	1·0919	12·976	9·400	141·226
11	·9226	1·0839	14·011	10·188	167·091
12	·9284	1·0771	15·042	10·974	195·012
13	·9334	1·0714	16·071	11·757	225·001
14	·9376	1·0665	17·099	12·539	257·059
15	·9414	1·0623	18·128	13·320	291·198
16	·9447	1·0585	19·152	14·100	327·382
17	·9477	1·0552	20·177	14·878	365·627
18	·9504	1·0522	21·199	15·654	405·909
19	·9527	1·0496	22·222	16·431	448·265
20	·9549	1·0472	23·244	17·207	492·664
21	·9569	1·0450	24·264	17·980	539·094
22	·9588	1·0430	25·281	18·754	587·551
23	·9604	1·0412	26·300	19·527	638·060
24	·9619	1·0396	27·322	20·300	690·652

[illegible] FACTORS

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Size*	Distance [illegible] Factor	Distance [illegible] Factor	Distance [illegible] Factor
	f = [illegible]					*F* [illegible]		
1	[illegible]	[illegible]	[illegible]	[illegible]	1	3·51	4·3?1	5·22?
¾	[illegible]	[illegible]	[illegible]	[illegible]	¾	2·338	2·781	3·237
½	[illegible]	[illegible]	[illegible]	[illegible]	½	1·462	1·625	1·803
0000	[illegible]	[illegible]	[illegible]	[illegible]	0000	1·362	1·495	1·634
000	[illegible]	[illegible]	[illegible]	[illegible]	000	1·252	1·344	1·445
00	[illegible]	[illegible]	[illegible]	[illegible]	00	1·173	1·238	1·311
0	[illegible]	[illegible]	[illegible]	[illegible]	0	1·121	1·165	1·215
	f = 20					*f* = 40		
1	[illegible]	2·771	3·261	3·768	1	4·2447	5·2661	6·2961
¾	1·6?4	1·865	2·116	2·378	¾	2·7520	3·3072	3·8719
½	1·1??	1·263	1·351	1·411	½	1·6342	1·8480	2·0726
0000	1·146	1·206	1·271	1·341	0000	1·5033	1·6753	1·8570
000	1·100	1·130	1·184	1·233	000	1·3566	1·4808	1·6136
00	1·067	1·093	1·123	1·155	00	1·2493	1·3371	1·4326
0	1·046	1·063	1·084	1·106	0	1·1747	1·2345	1·3023
	f = 25					*f* = 60		
1	2·7651	3·38?6	4·012	4·642	1	6·2681	7·8194	9·3778
¾	1·8?00	2·200	2·513	2·885	¾	3·9738	4·8334	5·6995
½	1·285	1·303	1·513	1·637	½	2·1817	2·5365	2·9009
0000	1·22?	1·306	1·300	1·408	0000	1·9583	2·2505	2·5527
000	1·152	1·210	1·270	1·345	000	1·7002	1·9104	2·1480
00	1·101	1·112	1·187	1·235	00	1·5040	1·6651	1·8352
0	1·071	1·097	1·127	1·100	0	1·3503	1·4763	1·6019

[illegible]find true drop in line, multiply ohmic drop by factors in these tables.

* Diameter in inches, Gauge Brown & Sharp.

IMPEDANCE FACTORS.

Dia.* and Gauge.	Distance 6 in. Factor.	Distance 12 in. Factor.	Distance 24 in. Factor.	Distance 48 in. Factor.
	Frequency *f* = 80			
	8·3108	10·387	12·474	14·557
	5·2244	6·3840	7·5478	8·7151
	2·7720	3·2649	3·7339	4·2722
00	2·4577	2·8683	3·2873	3·7119
00	2·0884	2·4024	2·7249	3·0536
00	1·8011	2·0376	2·2825	2·5355
0	1·5833	1·7507	1·9451	2·1373
	f = 100			
	10·362	12·919	15·573	18·182
	6·4873	7·9445	9·4039	10·869
	3·3829	4·0118	4·6474	5·2874
00	2·9793	3·5060	4·0400	4·5787
00	2·5004	2·9078	3·3225	3·7426
00	2·1227	2·4341	2·7528	3·0794
0	1·8316	2·0679	2·3130	2·5642
	f = 130			
	13·444	16·832	20·227	23·623
	8·3925	10·295	12·191	14·104
	4·3185	5·1487	5·9842	6·8233
00	3·7828	4·4814	5·1860	5·8942
00	3·1426	3·6878	4·2387	4·7939
00	2·6316	3·0529	3·4808	3·9161
0	2·2328	2·5567	2·8898	3·2283

Dia.* and Gauge.	Distance 6 in. Factor.	Distance 12 in. Factor.	Distance 24 in. Factor.	Distance 48 in. Factor.
	Frequency *f* = 25			
2	7·7038	10·37	12·012	15·55
1½	5·014	6·454	7·831	9·017
1	2·7654	3·3826	4·012	4·642
¾	1·889	2·209	2·543	2·885
½	1·285	1·393	1·513	1·637
0000	1·222	1·3068	1·3606	1·408
000	1·152	1·2104	1·2703	1·345
00	1·1034	1·1422	1·1870	1·235
0	1·0710	1·0973	1·1277	1·160
1	1·0478	1·0676	1·0853	1·108
2	1·0324	1·0443	1·0583	1·071
3	1·0216	1·0293	1·0384	1·048
4	1·0142	1·0191	1·0247	1·031
5	1·0094	1·0126	1·0162	1·0203
6	1·0063	1·0084	1·0107	1·0134
7	1·0042	1·0055	1·0070	1·0087
8	1·0027	1·0035	1·0045	1·0056
9	1·0018	1·0023	1·0029	1·0036
10	1·0011	1·0015	1·0019	1·0024

To find true drop in line, multiply ohmic drop by factors in these tables.

* Diameter *in inches*, Gauge Brown & Sharp.

[illegible] We now get a [illegible] and [illegible] of turbines and the [illegible] of the turbines themselves. [illegible] I am glad to think that the papers [illegible] and myself fifteen years ago [illegible] a small portion of the attention [illegible] Professor Forbes has referred to one of them [illegible] published about the same time which [illegible] anybody since it was published, which [illegible] to a distance merely, but to the [illegible] which distributes the power all [illegible] of power per mile. We had [illegible] in connection with the telpher scheme we were [illegible] at that time, and we got out most interesting results, which I think [illegible] study at the present time. I am not sure that I quite understand why Professor Forbes is trying so much to keep up the [illegible] but I suppose this is due to the fact that I have not had time for [illegible] study of the paper. Professor Forbes speaks of the great [illegible] in the transmission when you have a less efficiency than [illegible] per cent. To me this is a very interesting statement, because Professor Ayrton and I proved in 1880 to our own satisfaction — I do not know whether anybody else has studied it — that it is not possible [illegible] at a less efficiency than [illegible] per cent.

Professor Perry.

[Professor FORBES: That is just what I am showing you how to accomplish.]

I see that one section of the paper is devoted to the Booster method of working, and as I say, I have not had time to study it in detail, and as my old work is certainly right I do not see why I should not refer to it. In regard to the author's commendation of his method, would it be too much to ask whether it is not possible that Professor Forbes is neglecting a rather important question in this matter of boosters, viz., that the power that is transformed in a booster costs money for its transformation. When you want to keep up the voltage you can do so by increasing the copper in a conductor or by using a booster. Now when you increase the copper, what you do is to save power at the expense of copper; when you use a booster you create power in the current that goes on at the expense of the current that is lost and at the expense of a machine. In both cases you may be said therefore to create power or prevent waste of power at a certain cost. I may say that some time ago I went into this matter of comparison between cost of the booster and the cost of copper in a conductor for keeping up the voltage. Of course the booster will do what no increase of copper will do. You can raise the voltage as much as you like by means of a booster. But suppose there is a drop in a conductor. Suppose you have a conductor, for example, which has been designed on the Kelvin rule, and you have a certain drop of voltage with your current. Now suppose you want to diminish that drop, you can do it by increasing your copper, you can do it by having a booster. Which is the more economical? Well, it depends greatly on what diminution of the drop you want to produce. Secondly, on what is the cost of the power transformed or developed by the booster. Suppose we take it that the transformation or development of power in a booster costs s times as much as the power direct from the generator. We take it that the booster costs money, that it needs attention, that there is rent, in some cases there is special ground for it, and a building and so on. Suppose we want to make a drop of voltage one mth. of what it is already. Then I find the cost, first without a booster or any other plant and the old drop, secondly with sufficient copper alone for the lessened drop, thirdly with the old conductor but with a booster to get the lessened drop, to be in the proportions of 2 and $m + \frac{1}{m}$ and $2 + s\left(1 - \frac{1}{m}\right)$. If I may be allowed, I will give this document which I hold in my hands to the Secretary for publication at the end of these remarks. It contains some results of the consideration of these proportions. It appears that, in many cases to use a booster is not so economical as the use of more copper.

[The following is the document referred to by Professor Perry. —ED.]

"By giving probable values to m and s, we easily find the relative merits of mere copper and of the booster. The value to be chosen for s depends greatly on the nature of the work. In most cases s ought to be taken *greater than 2, or even* greater than 3. It is not only that the *booster costs money, and takes* up space and men's time and attention,

[illegible] does not know.

[illegible] of 150 H.P.

[illegible] work to the extent of

[illegible] Professor FORBES:

[illegible] It is unfortunate that I

[illegible] it, and one does not want

[illegible] than one can help; but I feel

[illegible] to tell you. The air-blast was not

[illegible] put on special troughs to receive it

[illegible] that they remained quite cool enough without

[illegible] perfect through them, and [illegible]

[illegible] which was [illegible]

patented in the United States as well, only the patent was refused for the usual reason, namely, that in those days inventors in that country were allowed to do what is called "swearing back," and whoever could swear back the hardest and give the earliest date, received the patent. Mr. Ferranti.

This is a paper which I should like to take the whole evening to discuss, because it is so interesting, but I will make a few remarks as concisely as possible. With regard to rotary converters, I notice that there is a very distinct tendency to drop these in favour of motor-generators. I am very positive about the advantage of motor-generators in one form or another as against rotaries. My opinion generally is, that rotary converters are very troublesome and tricky, and that they are more suited to water-power transmissions with perfect driving, than to the ordinary type of electrical generation by steam engines. I have seen American-built rotaries with the device described by Professor Forbes, namely, the short-circuiting pieces between the poles to receive the currents induced in them for the purpose of steadying, and I have seen them hunt about as badly as they could do, so that it was quite a clever business under some circumstances to keep them in step. Of course where the whole installation is perfectly planned out, it is not so difficult, but in comparison with other apparatus in the market the rotary converter is a tricky thing. With regard to motor-generators, I consider this class is quite the best to adopt for dealing with power at the end of a long line where it is to be converted into continuous current in motor generators. I am at a loss to understand why people should use induction motors. The principal thing in their favour appears to be the patent question. Broadly, if one had not any consideration of that kind one would prefer to use the synchronous motor for the motor-generator. The induction motor, as Professor Forbes has stated in his paper, has a bad power factor, and a bad power factor is the most serious fault possible in alternating-current work. When one sees how perfectly synchronous motor-generators hold in, and how thoroughly satisfactory they are in practice, one cannot understand why some people wish to force apparatus of this kind in preference to taking what is recommended, and what in many cases can be proved to be a first-class apparatus. Everything goes to show that the synchronous motor-generator is the best article for taking power transmitted from a distance, and turning it into continuous current.

Now with regard to multiphase systems, Professor Forbes has indicated clearly a most valuable feature. It does not appear to be generally realised what a valuable thing a two-phase system is, with its centre to earth as shown in the author's diagram. I have never come across any one who does not seem to be spell-bound by the idea that the way to transmit power is three-phase, and that three-phase transmission has this wonderful gift that nothing else can have, of transmitting power at the least possible cost. I am glad that Professor Forbes has shown the fallacy of that statement; it is a pity that some one had not thought of doing so before. In regard to the question of what is the best system to adopt for transmissions, it is quite certain, as Professor Forbes has mentioned, that the best system of transmission is not necessarily the

... I am satisfied ... perfect the ... an extent as ... The reason why I ... periodicity alter- ... simplicity. The switch ... multiphase systems are ... single-phase system. The ... cheaper to be able to use ... ated, and of course if ... are fewer conductors than ... generally a matter of ... things which make multi- ... I think that fashion ... having got the idea. ... Professor Forbes has said. ... whether there is anything better

... work abroad. We

question. Many people are struggling to-day, and working hard and spending their money, and risking it—because it is a great risk—to get permission to transmit high-pressure current all over this country for the benefit of manufacturers, and to put us upon an equality with other nations who have these advantages. Now the ordinary legal procedure, in the case where a man is accused of a crime, is for one man to prosecute him, but an able lawyer is always to be found who, however well convinced he may be that the man has committed the crime, is ready to do his best to get him acquitted. We do not want electrical engineers to follow on these lines, and I trust that when the Bills for Power Supply are being discussed that no electrical engineer will be fonnd to say one word against them or to do anything that will impair their chance of getting through. Mr. Ferranti.

We are in a backward enough condition in this country in the matter of power transmission, and it is the duty of every one in the country connected with the electrical industry to do all in his power to get the facilities which will enable us to get on a par with other countries.

Mr. G. L. ADDENBROOKE: There really is very little to criticise in Professor Forbes' paper, because one must so profoundly agree with it. It deals chiefly with long transmissions, longer probably than for some years will be employed in this country, and it is a great pity that these transmissions are not appreciated. From what I have seen in the Colonies there is a vast field for the transmission of power, but we have nothing of the same sort here, and one consequence of this is that manufacturers have nothing to guide them in the construction of plant, and they have not that incentive to go into it which arises from close contact. Most of these great undertakings arise not simply from manufacturers or from users, but from a combination of the two, the user helping the manufacturer to an enormous extent, and I do not see how any successful manufacture on a large scale of this sort of plant for use in other parts of the world can be carried on in this country unless there are opportunities of using it here. So much time is necessarily lost in correspondence with users of plant abroad that progress in manufacture must be slow. Manufacturers in Germany and in America have had several advantages; they have had a free hand for experimental purposes, and have carried out their experiments; they have been more or less on the spot, in many cases having transmission to their own works, and they have been able to get the data to carry out all this work. On the other hand, as Mr. Ferranti has said, it is a most deplorable fact that experiment in this country is absolutely prohibited. You can do nothing here electrically without going to the Town Council, and of course that means obstruction. If a scheme, which may be far advanced, is taken to a local authority, with a request for their permission to apply it, they are immediately in a fog; their advisers tell them that you are going to make a quantity of money out of it, and they then place all sorts of obstacles in your way, and impose such conditions that success is impossible. The consequence is that no experiments are tried here, and we are lagging behind, and the finest trade of the next half-century is being deliberately thrown away. Supposing in the days of railways the whole matter had been Mr. Addenbrooke.

Mr. Addenbrooke. put into the hands of municipal authorities, and supposing that no railways had been constructed without them, where would be the magnificent railways of the present day? This country would be in quite a secondary position. Yet we have a chance of standing in an equal, if not a better, position than our rivals, and we are absolutely and deliberately deprived, legislatively, of that opportunity.

I will not speak of the electrical portions of the paper, because I so entirely agree with Professor Forbes that it seems to me there is not much to talk about. The question whether things are to be done in two-phase or three-phase, or, as Mr. Ferranti says, in single-phase, is a secondary consideration. They can be done. We can have facilities and all sorts of advantages which will make our lives more comfortable and enable us to produce what we want more cheaply, and we do not want to quarrel whether we get it 5 per cent. cheaper in one way than another. We can do it to-day, and the point is that the legislature and Parliament and everybody should give all facilities for doing it. Unless we get some opportunities of that kind we shall never divert the capital of this country into such things. During the last three or four years I have been constantly asked by financial people in the City whether the Central London Railway would be successful technically. I have suggested their visiting the City and South London Railway, which has been running for so many years, but they never do. People doubt unless they have the evidence of their own senses, and so we shall not succeed unless we have an opportunity of experimenting in this country.

In conclusion, I should like to correct the very general impression that you cannot do respectable lighting work with three-phase power plant. I was very pleased indeed with some of the work I saw on the Continent about eighteen months since, where motive power and lighting were done off three-phase systems without the use of motor-transformers. I do not say that it was the very highest class of lighting, but lighting good enough for all practical purposes, except perhaps for the centre of a first-class town, was being done in a number of instances in that way. There is also this important fact, which is not perhaps altogether appreciated, that with a first-class engine driving an installation at constant speed and constant periodicity, and with a motor-transformer transforming the multiphase into continuous current, you may have very large variations of pressure on the line without affecting the continuous current equally; because as long as the periodicity remains the same, the rotary-transformer tends to go round at very nearly the same rate, only taking more current, and therefore, by such a system as this, very good lighting can be done with multiphase current, even when there are large variations in the voltage owing to power being taken off the mains by polyphase motors.

Mr. Esson. Mr. W. B. Esson: I should like to ask Professor Forbes if the booster system, as described, has been tested in actual working, and if he would oblige me with the references, in order that I may further inform myself with regard to the results obtained in practice. With reference to the working of Kelvin's law, might I suggest that there

must be taken into account not only the cost of the copper, but that of the generators, and in fact of everything at the generator end, because it may so happen that, as in the case shown in the diagram, in generating 6 H.P. to get 1 H.P., the extra expenditure in generators, transformers, turbines, hydraulic works, and the like, would be far greater than the saving in the copper. Mr. Esson.

Referring to the matter of the phase rectifiers, might I suggest to Professor Forbes that the reason why the Oerlikon Company adopted these was not for the purpose of getting rid of the idle currents, but because the generators, being of the claw field type, were quite unsuitable, and had such a tremendous drop in volts that the Company had either to put in phase rectifiers to keep the pressure up, or to turn out the generators. I should also like to ask Professor Forbes if he could supply any figures which show the difference obtained by stranding the copper wire instead of having it solid, for the factor given in Table VII.

Mr. R. Hammond: The members of the Institution must all feel under a very great debt of gratitude to Professor Forbes for delivering what is really an epitome of a very ripe experience at this most important juncture. Next week five Power Transmission Bills come before a Committee of the House of Commons, and the question as to whether England is to have a long-distance transmission or not has some chance of early settlement. A very powerful committee, as the members are aware, has been formed, and whatever the preliminary skirmishing may have been during the past year or two, all feel that the question is one with which Parliament is going to deal, and, that being so, the laws governing long-distance transmission are attracting the very closest attention, and have the very greatest interest for members of this Institution. But I should like to emphasise the point that Professor Forbes has made, viz., the very great importance of a proper appreciation of Lord Kelvin's law. The same interest, the same mortgage value of interest upon copper will not do. On the one side the debit must be a fair amount of interest upon the copper. Professor Forbes suggested that it might be 15 per cent., but I do not think even the most sanguine promoters of the Power Bills are looking for as much as that, but a good solid round interest upon the copper, such an interest as may tempt financial people to put their money into the schemes before us. Then, on the other hand, Professor Forbes truly says that it is not only the mere loss of current *en route* that has to be taken into consideration as to what is to be lost on the other side. You have to consider the absolute cost of production, including the wear and tear of machines and so on. However, the discussion on Kelvin's law may perhaps with advantage be left to another occasion; but I urge that the remarks of Professor Forbes on this point are very well worthy of very careful consideration. Although Mr. Ferranti is of opinion that in the end the single-phase system will prevail, there is a popular idea that at present the power schemes will have to choose between two-phase and three-phase. Professor Forbes decides for two-phase, and it may interest the members to know that during the past fortnight I have spent a most Mr. Hammond.

Mr. Hammond.

interesting time in investigating two-phase and three-phase stations on the Continent, and (although of course the Continent may be wrong) I find that the Continent plumps for three-phase. There are many cases in which there are already single-phase works in existence, and where manifestly the network is much more suitable for two-phase, split up into two single phases, than for three-phase, as for instance at Vienna. The large station in that city is now being extended by two-phase plant, because that system is more suitable for use with its present network; but in new places where they have a clean sheet, such, for instance, as at Mannheim, they have throughout a three-phase station, and as Mr. Addenbrooke says, they have no difficulty not only in transmitting the three-phase current from a distant point to the centre of the city, but in distributing by means of low-pressure three-phase current both for power and for lighting. Professor Forbes has mentioned that in the two-phase system with common return one has an advantage in the cost of the cables, but I made very careful inquiries of Mr. Blathy, of the Ganz Company of Budapesth, and of other engineers on the Continent, and Mr. Blathy strongly objected to the use of the common return with a two-phase current; indeed, he went to the extent of saying, "If I had not to transmit from a distance at all, but had to lay down a station in the middle of a city, generating by low pressure, I would generate by three-phase low pressure, and not by continuous current."

I would like in conclusion to add two words, first with regard to Professor Forbes' splendid illustrations of long-distance work. When at Budapesth, they showed me an experimental car which is just a sample of what is now being done in the north of Italy, where they are about to run a full-gauge railway of 110 miles in length on the three-phase system; they are going to generate at 20,000 volts, with 15 periods; they will have converter stations ten kilometres apart to transform down to the low pressure of 3,000 volts, and will introduce that 3,000 volts into the motors on the car.

My other point is one strongly supporting both Professor Forbes and Mr. Ferranti in favour of motor-generators rather than rotary converters. I saw in Frankfort the whole of the tramways being run by motor-generators from a single-phase station. The single-phase current at 3,000 volts is brought to a central spot in Frankfort, and is there transformed by three motor-generators of 750 kilowatts, distributing a continuous current of 550 volts to the tramway. The latest thing in favour on the Continent is distinctly the use of motor-transformers rather than rotaries.

Mr. Swinburne.

Mr. J. SWINBURNE: The first question I want to raise is that of Lord Kelvin's law. When in 1881 Lord Kelvin's law was brought forward, people had apparently got hold of something new. The real novelty consisted in the simplicity. Lord Kelvin happened to deal with a case where the law is simple, and you could get a terse mathematical expression which gave you the best economy, and that was the Kelvin law. But the general law as to the most economical arrangement of investing capital in order to save

Mr. Swinburne.

revenue has been known to commercial men from the beginning of the world. The only difficulty is to calculate it. When you have something that you can calculate definitely you have Kelvin's law, but as soon as you begin to get into complicated departures from it you no longer have Kelvin's law, but you merely come into ordinary commercial calculations. What you have to do is not to make general laws of distribution, and then fit them to the particular town you have to deal with. The Germans do that a good deal. I have a German book on networks theoretically calculated out to fit any town—you have your town, and you hunt up the particular page in the book where the network fits, I suppose—but I have never read—only reviewed—it.

There has been some little misapprehension, I think, if I may say so, with regard to Professor Forbes' remarks about boosters. I do not know whether I can put the matter any more clearly in this way. If you are limited by law or anything else to use a maximum of, say, 10,000 volts—it does not matter what—if you cannot use more than that pressure you may start at your station with 10,000 volts, and let the volts fall as you go from the station, or you may put a booster in. In the latter case, as stated by Professor Perry, the power is put in at one end and taken out at the other, and its value is therefore enhanced. That is true, but the booster enables you to run with 10,000 volts all along, and hence the economy. I think the matter is perfectly simple if you look at it in that way. You always use in the system the highest volts permissible, instead of only using the highest volts at one end and letting it get low at the other. I do not know whether any of you ever beguile your leisure by tracing the origin of religious dogmas. It is a very interesting study, and I would like to deal a little in that direction with regard to the rise of the three-phase motor. Some time ago, especially in Parliamentary inquiries, there was always the reproach against the alternating current that there was no alternating motor. The problem of the day to be solved was the alternating motor. The technical papers every week or fortnight used to announce that the alternating motor problem had been solved afresh, but you could not get the alternating-current motor. Then came a number of people who professed to have solved the alternating motor problem, but they really had done nothing of the sort. They had introduced a new system of distribution which was capable of using a motor, but it was not an alternating motor in the sense understood—it was another thing paraded under the old name. It was not a solution at all. But it gave us something that would start, and the great difficulty was to start alternating motors. But that is only in the case of small motors. People have forgotten that these difficulties do not exist to the same extent when dealing with large motors such as there are in stations. People have commenced in this way, and they have used the motor for distribution in factories and so on, and it has grown. People like Mr. Hammond go to foreign countries, and they say, "Here are people all using three-phase motors: it must be right." So they go and use three-phase motors. Then somebody says, "Why, here is Mr. Hammond using three-phase motors: it must be right." Now of course there are really important questions when you consider the sizes of mains and of dynamos. But I think

Mr. Swinburne.

you will find it is really all a question of the size of mains. In dealing with the size of mains, the first thing to be certain about is that you are dealing with rational assumptions. You can make as many calculations as you like as to which is the most economical size of main, and all the various calculations differ considerably, because people start with different assumptions. If you really set down what you have to do, I think you can calculate your mains. I do not think the question of the size of the dynamo comes in; it is not very important. But I do think that freedom from breakdown is enormously more important than the efficiency in most of the cases. In large transmissions the capital spent in copper and insulation—the insulation being generally more important than the copper, although it does not come into Kelvin's law—is more important. Having got that, you can calculate it out in a commercial way, and if you keep your eye on the efficiency and the freedom from breakdown, I think, as I have always thought, if I may respectfully say so to Mr. Ferranti, that he has been right all along in what he has said to-night.

Professor Wilson.

Professor E. WILSON (*communicated*): In connection with Fig. 4, I should like to point out the relative advantages of two- and three-phase systems when working (1) on the assumption of constant-current density, (2) on the assumption of constant ratio between the power received from and the power delivered to the transmission line.

(1) CONSTANT CURRENT DENSITY. *Two-Phase.* If there be four wires, the saving over the single-phase as regards copper is nil. The copper volume is proportional to the current, so that with three wires the volume will be $2 + \sqrt{2}$ as against 4; the saving in copper is 15 per cent.

Three-Phase Mesh Grouping. If there be six wires the volume of copper is 6 and the saving over the single-phase as regards copper is nil. The current is $\sqrt{3}$ in each line with three wires and potential difference undisturbed. The volume of copper is then $3\sqrt{3} = 5{\cdot}19$ as against 6; the saving is 13·5 per cent. The resistance is $\frac{6}{5{\cdot}19} = 1{\cdot}16$ times as great, but the currents are 13·5 per cent. smaller. The loss in transmission is $({\cdot}865)^2 \times 1{\cdot}16 = {\cdot}868$.

Three-Phase Star Grouping. If the windings were to remain the same as in the mesh machine, and simply connected star, the volume is only 50 per cent. of that required by six wires, but the potential differences are $\sqrt{3}$ times as great. By re-winding the machine so as to obtain the same potential differences between the line wires, the volume reduces as before to 5·19 as against 6 with single-phase, and the saving is 13·5 per cent.

(2) CONSTANT EFFICIENCY. $\left(\frac{\text{Line output}}{\text{Line input}}\right)$

For a given length the resistance varies inversely as the cross-sectional area: the volume varies inversely as the resistance. Consider a three-phase system, and assume that the efficiency is to be the same with three wires as with six wires. Since the power to be transmitted is to be the same, the currents and potential differences must remain the same. For the same loss the resistance must be increased and the volume decreased.

that is, the resistance will be 1·34 times and the volume ·75 times. The drop in volts will now be 1·16 as against 1·00 with constant current-density. Professor Wilson.

It seems to me that the proper basis of comparison is the maximum potential difference between any two-line wires, and I should have thought it quite consistent to call the two-phase system (Fig. 4) a 20,000-volt system. From the paper I gather that the two phases in the Niagara generators are quite separate, but if the centre of each system is put to earth (Fig. 4) the advantages mentioned in the paper of keeping to separate phases are done away with. On the other hand, by insulating both phases from one another, there is the possibility, in the event of one wire getting to earth, of any one at earth potential receiving the maximum potential difference of the system.

Mr. M. B. FIELD (*communicated*): I would like to add a few remarks to those of Professor Forbes on two- *versus* three-phase. The following figure shows a single-phase, three-phase, and a two-phase system, each with the centre point earthed. The two-phase we may consider as a four-legged, the three-phase as a three-legged, and the single-phase as a two-legged system, the power generated in each leg being V × C × power-factor. The total power generated in the respective cases will be V × C × power-factor × number of legs. On this basis, of course, the weight of copper per k.w. in the transmission line for a given percentage loss must be practically the same whether the system be a two-legged, five-legged, or a twenty-legged system. Moreover, in each case the maximum voltage above earth is V, that is, the strain upon the insulation is the same. Mr. Field.

This is what I take Professor Forbes' argument to be. It is hardly necessary to point out that this argument is only applicable where the centre of each system is earthed.

Take, for example, a single-phase system, and a three-phase system with three independent phases and six line wires, the voltage of each phase being V, both systems being completely insulated. The three-phase system corresponds to three single-phase circuits, and manifestly the cost of transmission in each case is the same. Next group one wire of each circuit of the three-phase system together, and we find that down this fourth wire no current flows. We therefore dispense with it. We have thus halved the amount of copper in the three-phase system, halved the line losses, but *have not doubled the voltage* between the line wires. The maximum voltage is now only 1·73 V. In the single-phase case, if we halved the copper and halved the line loss, we should have to *double the voltage* to transmit the same amount of power.

In other words, supposing any point of the single- or three-phase system may become accidentally earthed, and we are to keep the maximum possible potential above earth, which may occur under such circumstances the same for the two systems, the three-phase undoubtedly provides us with a more economical transmission than the single- or two-phase systems.

Now I would like to take up the two following points :—

(1) Is it generally good practice to earth the neutral point of the system?

Mr. Field.

(2) Even when the neutral point is earthed, are the two- and the three-phase systems really on the same basis as Professor Forbes would indicate?

First, then, Professor Forbes has laid great stress on continuity of supply. Now, from my own experience I can assert that I have been able several times to tide over a difficulty and avoid a discontinuity of supply from a system whose neutral point was not earthed, where this would have been almost impossible had the reverse been the case.

Consider a station in which the generators are supplying direct, without step-up transformers, the high-tension overhead line, and a lightning discharge in the neighbourhood induces an extremely high potential difference between certain line wires and earth. For some reason the lightning arresters fail to protect the generators, and a spark pierces the insulation of an armature coil and jumps to frame. This

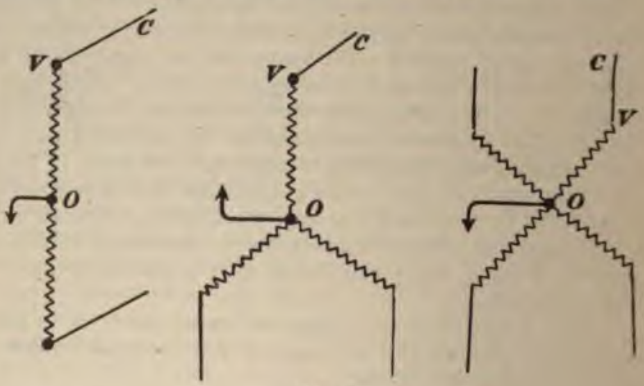


FIG. A.

almost always occurs near one terminal of the generator, the inductive effect rarely traversing more than one or two turns of the first coil before it discharges itself to earth by a spark piercing the insulation. If now the neutral point be earthed, a violent short occurs in one part of the generator armature, an arc inside the faulty coil is instantly started which in a very short time effects grave damage. If, on the other hand, the insulation of the generator be otherwise good, the neutral point may be merely displaced from its normal position. The amount of displacement depends on the effectiveness of the earth formed in the faulty coil. Under these circumstances I have been able on several occasions to keep a generator in circuit till the heavy load on the station has sufficiently subsided for the faulty generator to be switched off and repaired without any discontinuity of the supply whatever.

With regard to the second point I have raised, while I recognise with Professor Forbes that the important danger along the line (neglecting shorts due to malice) is that of leakage, which is the same whether the two-phase or three-phase system be employed, provided the neutral is earthed, I maintain that the line is not the only part of

the system where trouble is to be looked for. Nowadays the tendency is to generate higher and higher voltages in the armatures, and to dispense with step-up transformers. This necessitates switchboard apparatus capable of dealing with very high-tension currents. The design of such apparatus is at best difficult, and very serious arcs may be started between neighbouring bus-bars, terminals, etc., not necessarily directly connected therewith, should such apparatus work imperfectly. The greater then the actual difference of potential between the bus-bars and terminals on the switchboard, the greater must be the precautions taken to avoid trouble from shorts and arcs forming directly between them; and this is quite independent of the fact that the neutral point of the system may be earthed. Mr. Field.

Professor Perry asked about the size of synchronous motors necessary to produce a definite phase-rectifying effect, and a few words on this head might be of interest.

In one station for the supply of motive power, with which I was connected some while back, the generators (*A*) had a very drooping characteristic on account of their large armature reaction and self-induction, and from economical considerations it was deemed expedient to work them at such a voltage that the power obtainable from them at that voltage was considerably less than the power obtainable from the turbines to which they were direct coupled. When subsequent extensions were necessary, it was proposed to install generators (*B*) capable of considerable over-excitation, so that these would supply the whole wattless component of the current leaving the station. The generators *A* would thus not be supplying a lagging current, but one in phase with the bus-bar voltage, *i.e.*, their load would correspond to a load of lamps, in which case, of course, the power obtainable from them would be considerably increased. This was, in fact, actually carried out. The first batch of generators *A* installed were coupled each to a 300-H.P. turbine; the extensions consisted of large generators (*B*), each coupled to two turbines of 300 H.P., and so designed that one generator would supply, over and above its normal load, the idle current for three of the type *A* machines. By over-excitation of the generators *B* it was not only possible to arrange that the *A* machines supplied merely a current in phase with the bus-bar volts, but *B* might be still further excited so that *A* supplied leading currents, which of course tended to raise the terminal voltage above the normal. In this way the normal voltage could be maintained at the bus-bars, while the generators *A* were loaded up to the full output of the turbines to which they were coupled.

For example, suppose the power-factor of line and receiving circuits was 0·7, and the generators *A* had reached their limit when their input was 200 H.P. each (*i.e.* beyond this they were no longer capable of maintaining the voltage). Suppose further that three generators *A* were supplying power for the line and each was loaded up to its limit, then if one generator *B* were started up and switched in parallel, and its turbines supplied with just sufficient water to run it light, it was possible *to so manipulate* its excitation that without it supplying any

Mr. Field. actual power to the line, the bus-bar voltage could be maintained at the normal figure, while each of the generators *A* were loaded up to the full extent of their respective turbines; in fact, the extra excitation necessary for the generators *A* was supplied by wattless armature currents derived from the generators *B*.

It is, of course, clear that the generators *B* had to be designed most liberally, and except in exceptional cases such a procedure would be far too costly to pay.

Suppose, for instance, a generator is working on a power-factor of 0·7, then the wattless current is equal to the watt current. To rectify this completely a synchronous motor would have to be installed capable of taking up a current equal and opposite to this idle current. Or we may consider this motor as a generator running round light and connected to the receiving end of the line, so that it supplies to the receiving circuits the lagging idle currents demanded by them, while the actual generator supplying power at the other end supplies to the line merely the watt component. The two ideas are identical. It is clear then, that the motor must be *electrically* a larger machine than the generator, for it is acting as a generator capable of maintaining its voltage while supplying the full-load current on a pure inductive load, whereas the actual generator in all probability would not do so. The cost of such a phase-rectifying motor would therefore be greater than that of the generator, were it not for the fact that the motor may safely be run at a very high speed. We thus see that except for very long lines where the prime cost of the generating plant is an insignificant item, the plan of using unloaded synchronous motors as phase rectifiers must be a very costly one.

Mr. French. Mr. A. H. French [*communicated*]: As Professor Forbes has suggested that accounts of Power Transmission Plants might appear in the discussion, I append from memory a short note on the continuous-current transmission plant at Genoa, as it was running in the year 1895. The scheme was originally suggested by Signor Bruno, who carried out the water-power part of the work, constructing a large reservoir by damming up a tributary of the Po, just above Isoverde, about 16 miles from Genoa. A tunnel was then made for supplying the turbines, in the course of construction of which a great spring was found, sufficient to work several of the machines in the generating stations long before the reservoir was finished. The electrical work, at first carried out by an Italian electrical engineer, was a failure, owing, chiefly, to the constant breaking down of the armatures of the generators, caused by lightning striking the transmission line and finding its way to earth through the machines, and the generating station was shut down for a time. The work was afterwards very successfully carried out by Monsieur Thury, who equipped two generating stations, each consisting of about 360 k.w., being made up of four 150 H.P. Picard turbines, each one coupled to two generators of an output of 45 amperes at 1,000 volts. These machines were all run in series, and were mounted on large insulators cemented in the ground, the holding-down bolts being sulphured in. The coupling to the turbines was flexible, the connection being made with stout indiarubber bands. The generators were

Mr. French. at first separately excited, and were regulated by a solenoid fixed in series with the transmission line, the core of the solenoid operating the governor of the exciting turbine. This means of regulation failed owing to the frequent breaking of the transmission line, which then caused the exciting current through the generators to be increased so much that the whole of the generators were pulled up and the elastic couplings broken. This was afterwards remedied by adopting series-winding for the generators. This was also beneficial when a short-circuit occurred on the line, the machines then losing their excitation automatically. The working of the stations was so simple that they could be operated by any intelligent man without electrical training; for instance, when another machine was required to be put on the load, the dynamo was run up on the short-circuit switch until the current on the line was reached, the switch was then opened and the regulator did the rest of the work. This was effected by a motor, the shaft of which was coupled to all the turbine-governors, and which rotated either way, being worked by a relay wound in series with the transmission line, and the motor only remained stationary when the normal working current was reached.

The two generating stations could have been run in series up to a voltage of 16,000 volts if the insulation of the line had been good enough, but in practice 9,000 volts was not exceeded. The line was badly constructed, and not infrequently broke down through the collapse of the supports. On one occasion the plant was run for two days and nights with several poles lying on the ground (but the wires not touching the earth) close to a small village.

All the steam-plants in the factories along the transmission line were superseded by motors, and the central station at Genoa was solely worked by these motors. In connecting to the overhead wires the line was cut and the two ends taken to the motor and switch. Every motor was mounted on insulators; in starting, the short-circuit switch was opened, the line was then completed through the motor; regulation was effected by a governor which automatically altered the windings of the fields in such a way as to weaken or strengthen the opposite pairs of poles by gradual alteration of polarity. The brushes of the motors, as were also the generators, were of carbon and were self-adjusting.

Elihu-Thomson lightning arresters with condensers were used; at first much trouble was experienced through the condensers becoming overcharged and shattered during bad thunderstorms. At first a heavy thunderstorm was so terrifying that the assistants frequently suspended operations whilst it lasted. In all, the scheme was a great success, and had the line of transmission been properly constructed, a breakdown would have been a rare occurrence.

Mr. Kempster. Mr. J. W. Kempster [*communicated*]: With regard to efficiency consideration will show that (1) where the voltage at generating end of line is constant, a given H.P. is delivered with the least line copper at 50 per cent. efficiency, and it would be uneconomical to work below this; (2) with a fixed *voltage at receiving* end, and variable at the power station, *lower efficiencies would not* necessarily be wasteful. Boosters placed

Mr. Kempster.

at points along the line combine some features of both (1) and (2), and would be advantageous when the transmission line is of such a length that the limits of practicable voltage are reached; as apart from saving copper, the line pressure is minimised.

From the figures given in the tables it does not appear, however, that such low efficiencies as 50 per cent. are within range of commercial practice until very long distances of, say, considerably over 500 miles, are reached, with the pressure actually attained of 40,000 volts, and it may reasonably be anticipated that the difficulties incidental to still higher voltages will be overcome.

I estimate that 10,000 kilowatts transmitted 500 miles at 40,000 volts, with 50 per cent. line efficiency, would cost roughly £9 per E.H.P. per annum delivered, assuming the high load factor of 38, and making fair allowance for depreciation, with 4 per cent. interest. At 75 per cent. line efficiency the cost on a similar basis would be only £8 7s. per E.H.P. per annum, the lower capital outlay on hydraulic works and generating plant more than compensating for the extra copper. With boosters the figure might be reduced to £8, but against this saving of 7s. must be set the increased risk of breakdown.

For comparison I might mention the case of a textile manufacturer in Northern Italy, situated at less than 150 miles from the seaboard, who on a careful calculation finds that he pays £12 per annum per steam B.H.P., using economical compound Sulzer engines of several hundred horse-power.

Professor Forbes.

Professor GEORGE FORBES, in reply, said: I am really overwhelmed with the remarks of the President, which were somewhat too flattering with regard to the paper; and the remarks which one or two others have made on the merits of the paper were far beyond what I expected to hear from them. But I am very glad indeed if my humble contribution does serve any useful purposes, and I think that possibly some of these tables at the least will be of practical use to members. The booster method, as referred to in the paper, will have its chief applications in cases where the cost of generating power is small, and where the electric pressure is not excessive.

Taking the remarks that were made in order, Professor Perry says he wants some more figures given as to the size of phase rectifiers that must be employed for doing special work. Well, I have distinctly disclaimed trying to act as a professor, and to teach a class-room here the elements of engineering. I am sure Professor Perry does not need to be taught how to calculate the size of the phase rectifier for that purpose, and I should have thought there were very few electrical engineers in this room who were not perfectly competent to do that for themselves. As to his remark about boosters, he very aptly commenced by saying he did not understand them, and his subsequent remarks made that still more obvious. I confess that I find my own ignorance to be profound in attempting to distinguish between what is and what is not elementary in problems of electrical transmission. The remarks of several members have rather surprised me. I thought that the booster method was very elementary work, and that no difficulty would be found in seeing the point. It appears that to some present the method is not so clear. But

Mr. Swinburne made the whole thing about as clear as possible, and I need not say anything more about that. Professor Forbes.

I am sure we are all indebted to Mr. Ferranti very much for his remarks, historical, practical, and prophetical—historical in the past, practical in the present, and prophetical in the future. With regard to the air-blast transformers, I am very glad to have the information he has given. I daresay I had the information once, but I am sorry to say that I had forgotten it. His remarks about the benefit of motor-generators are of value to us all, and I am sure we shall all give great weight to them. Also his prophetical enunciation about single-phase low frequency transmissions are pregnant words that will bear fruit, I hope, in the minds of many people. I do not say that I support him entirely in that. I am not given to following too much in well-worn grooves, and I do not think that this reason can be given why I am not his follower at this moment in that idea, though I daresay he is perfectly right, and I should be ready to admit it as soon as I have had further evidence to convert me.

With regard to Mr. Addenbrooke's remarks, I do not know that there was anything that I need answer. Mr. Esson asked me whether there was any booster system used in the world. Boosters are used, but I do not know that Mr. Esson would be any better off in his facility of studying the advantages and disadvantages of the booster system by seeing one at work. I do not know of any booster system that is at work in the way and for the purpose described in this paper in any part of the world. He also spoke about phase rectifiers. I thought it was generally known that manufacturers abroad when making tenders for such work, frequently propose the adoption of such phase rectifiers to supply the so-called wattless current which is required by the motor, and which is used in exactly the same way as the Oerlikon ones were used, which every one knows of. Also, I presume, every one knows that these phase rectifiers do work. Whether they are economical or not depends upon the special case, and upon their cost. Mr. Esson asked me another question as to stranded *versus* solid wires in their effect upon the lag factor. I do not think there is any difference between them so far as the lag factor which I have been discussing is concerned, but the great difference comes in where you are dealing with what we have usually called skin resistances. Those are all the questions that Mr. Esson wanted to be answered, I think.

Mr. Hammond says that since the Continent plumps for three-phase, therefore three-phase must probably be right. That remark supports the contention that I put forward in my paper, that many people would be saying this, and that because when I leave a specification free on this point I am always getting in tenders for three-phase, I could perfectly well see that there was a stereotyped way in which people were going to work in their tenders. But it does not in the least follow that three-phase is the best, and I think many of us are agreed on that point, that it is not necessarily so.

I think I have answered every question which was put to me, and I have only to thank the speakers most heartily for the consideration which they have shown me, and the kind way in which they have received the paper.

Professor Forbes.

[Addition, May 21.—I notice in the corrected report of Professor Perry's remarks that he holds to his statement that when using no boosters you cannot transmit at a less efficiency than 50 per cent. At the time I thought that this must be a slip of the tongue. Space need not be here taken up in showing the fallacy of the statement. The calculations of the same speaker regarding boosters are of no more than academic interest.

I have read the remarks communicated in writing to the Secretary by Professor E. Wilson and Mr. M. B. Field, which deal with the relative merits of two and three phases and the earthing of the middle point of the electric system, and with phase-rectifiers; also Mr. J. W. Kempster's remarks on boosters. The questions raised are viewed in different lights by different engineers. I have no desire to force my own views, or even to impress them, on others. Each engineer founds his opinions on his own experience, and on what he has seen of the experience of others, and it is thus that his work is stamped by his individuality. Each of us must solve these problems for himself, and not by being told what A or B thinks is best. I have not attempted in this paper to convert any one to my views, and shall be well content if I have supplied material worthy of careful consideration.]

The President.

The PRESIDENT: Before I ask you to return a formal vote of thanks to Professor Forbes for this epoch-making paper which he has communicated to us, I would like to be allowed to say two words as to a matter that has struck me greatly in the course of this debate. Professor Forbes struck a note concerning the national importance to us at this crisis that electrical engineers should appreciate the advantages of power distribution on a large scale. That note of national importance was emphasised by Mr. Ferranti, and touched upon by Mr. Hammond. It has been alluded to, I think, by more than one other speaker, and it is one which I feel very strongly upon at the present time, now that these Parliamentary schemes are approaching discussion. We have here a problem that cannot be faced from the small and parochial point of view. Last autumn I visited not only the station at Paderno and that of Rheinfelden, but I also went further South, and visited a new station at Vizzola. It is a water-power station, taking about 20,000 to 22,000 H.P. from the water that flows from the Lago Maggiore. It is not to supply the City of Milan, which is only 27 miles away. Milan is supplied with light and power from Paderno, further east, which takes its power from the waters flowing from the Lake of Como. The Vizzola station is erected for power-purposes in the surrounding district of Lombardy. I am told that half the power was contracted for before the station had a single dynamo put into it. It has to provide power for the industry in the flourishing towns, of which you may never possibly have heard, of Gallarate, Busto Arsizio, and similarly of Legnano and Saronna. I think, with the exception of Legnano, I had never heard of any one of these towns until I went there. It was explained to me that this piece of Lombardy is the Lancashire of Italy, full of cotton mills, silk mills, and of various industrial enterprises which require power. They are shortly to have that power distributed to them electrically from their central station

The President.

at Vizzola, at high pressure, and by consent of the local authorities and under legal authority from the Italian Government. Now we have to compete in this country with these manufactures in the North of Italy. Are we to be debarred, by want of proper legislation, from being allowed to get our power from the coal-fields distributed electrically and economically in the same way as cheap power is distributed at Niagara and Rheinfelden, at Vizzola and other parts of the world? If Parliament is going to debar us from that, it will be little short of a national misfortune. I ask you to give your special thanks to Professor Forbes for this most timely and most important paper.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Associate Members:

William James Fletcher Freeland.
William Walter Hughes.
James Robert Percival Lunn.
Alfred Forbes McCann.
John Maclean.
John Russell Salter.

Associates:

John Burns.
Percy Dewhirst.
John William Ewart.
T. Frank Courtier-Forster.
William Golledge.
Christopher Holden.
Thomas McGill.
Herbert Seaborne Rawlings.
Edwin Rorke.
Ernest Marmaduke Sellon.
Hugh Sharman.
Tom Fleetwood Tate.
Joseph Geary Wilson.

Student:

Hugh Ledward.

GLASGOW LOCAL SECTION.

Paper read at Meeting of Section, March 23rd, 1900.

METHOD OF CHARGING FOR PUBLIC SUPPLY OF ELECTRICITY.

By W. W. Lackie, Member.

All Municipal and Company station engineers have considered more or less the existing methods of charging for a public supply of electricity. This has not been so much the case, however, with manufacturing and contracting engineers, unless where they have had supply stations to run, presumably because circumstances do not so immediately press the problem on their notice.

In order to get at the basis upon which the various methods at present in use are founded, it is necessary to consider (1) the cost of the different parts that go to make up an electric power station; and (2) the cost of generating the energy. No two cities will give the same cost for all the different items that go to make up either of these, but in order that we may have figures which will not only be of interest, but with which I shall be able to deal with some ease and freedom, I will take the costs of the Glasgow Corporation Electricity Department. As practically the greater number and certainly the most important of the items vary with the kilowatt-capacity, it is customary to state these at the cost per k.w. (one kilowatt, or practically $1\frac{1}{3}$ h.p.).

The first item in the capital cost of the power station is "Land and Buildings." This item is of course particularly subject to variation, according to the local price of land, labour, and building, but the average cost of the three generating stations in Glasgow is approximately £14 per k.w.

The next item is "Machinery and Plant," which includes boilers, steam-piping, engines, dynamos, pumps, travelling cranes, switchboards, and all accessories to complete the station proper, and will come to approximately £25. Accumulators stand at present at £2 per k.w. This practically completes the statement as to the power station, the

only other items being instruments and switchboards, which will be accounted for later.

The outside work consists of feeders and distributing mains. It is the largest item and is practically £45 per k.w. at present, although no doubt this will be very much less in due course. Meters account for £4 per k.w.; instruments cost 18s. per k.w.; and counting-house furniture and fittings come to 2s. per k.w. This gives a total cost of—

	£	s.	d.	
1. Land and Buildings	14	0	0	
2. Machinery	25	0	0	
3. Accumulators	2	0	0	
4. Mains and Cables	44	0	0	
5. Meters	4	0	0	
6. Instruments	0	18	0	
7. Counting-House Furniture, etc.	0	2	0	
Total	£90	0	0	pr. k.w.

We next come to consider the annual cost of each of these items, *i.e.*, the depreciation to be allowed on each of them. It has been the custom in Glasgow to rate and allocate this depreciation as follows:—

		£	s.	d.		£	s.	d.
1. Land and Buildings ...	1 per cent. on	14	0	0	=	0	2	9
2. Machinery	7½ " "	25	0	0	=	1	17	6
3. Accumulators	10 " "	2	0	0	=	0	4	0
4. Mains	2½ " "	44	0	0	=	1	2	0
5. Meters	6 " "	4	0	0	=	0	4	9
6. Instruments	5 " "	0	18	0	=	0	0	11
7. Counting-House Furniture	5 " "	0	2	0	=	0	0	1
		£90	0	0		£3	12	0

This gives an annual cost per k.w. of £3 12s., or an average cost of just 4 per cent. on the capital. There is further interest on the capital at the rate of 3·1 per cent., and a Sinking Fund to be allowed for at the rate of 1 per cent., which, together, make a total of 8·1 per cent. on the capital, or a cost of £7 5s. 9d. per k.w. of plant, no matter whether the plant is used for supplying 1 unit or 8,000 units. It is therefore clear that any consumer who applies to the

Supply Company and causes one k.w. of plant to be put down, and whose bill is under £7 9s. 5d. per annum, does not pay the bare cost of the upkeep of the plant, not to mention the actual cost of generation, *i.e.*, the cost of coal, oil, etc. These are the chief items which go to make up what are called the Standing or Stand-by Charges. Other items which might fairly be added to the stand-by charges are the rent, rates and taxes, and part of the management expenses. If these items are added, the above figure is increased by £1 10s. 3d., and the standing charges are brought up to £8 16s. If the items last mentioned are omitted, it simply means that the actual cost of the unit will be increased.

The items included in the actual generation of the current practically vary in proportion to the units generated, and are coal, oil, waste, water and stores, wages of workmen, repairs and maintenance. The cost of these items in Glasgow for the past year was as follows :—

Coal	·54d.
Oil, etc.	·06d.
Wages	·26d.
Repairs	·42d.
	1·28d. per unit.

I understand that Mr. Wright, of Brighton, not only puts under the head of Standing Charges the items I have mentioned, viz., depreciation, interest, sinking fund, and management, but he also includes stand-by coal charges used for banking fires, etc., and all wages of workmen. In this I think Mr. Wright is taking an extreme view, and I submit that a portion of the wages of firemen, enginemen, and engineers should go to the running expenses.

At this point there are three figures which it would be well to note specially: (1) the amount of kilowatts of the consumer's application, (2) the maximum demand of all the consumers added together, and (3) the greatest demand made on the station at times of full load. The maximum demand of all the consumers added together is equal to about 70 per cent. of their aggregate application, and the ...um demand made on the station is about 50 per cent. ...l power applied for. If the standing charge of

£8 16s. per k.w. of plant in station is to be proportional to the consumer's application, the charge should be £4 8s. per k.w. of application; if according to the maximum demand of the consumers, the charge will be £6 4s. *plus*, in each case, a charge to cover the cost of generation per unit. Take it that it is to be proportional to maximum demand, *i.e.*, each consumer is to pay £6 4s. per kilowatt, *plus* in each case a charge to cover the cost of generation per unit of maximum demand as his share of standing charges *plus* a sum of, say, for the present, 2d. per unit to cover the cost of generating the current. The system of charging adopted in Glasgow allows of this £6 4s. being paid practically in three ways—certainly in two. It may either be paid in twelve equal monthly instalments of 10s. 4d. per k.w., or it can be paid in 365 equal payments of 4d., *i.e.*, on the first 365 units per k.w. *plus* in each case 2d. per unit. This last case we are all familiar with. It corresponds to the first system of charging for 200-volt supply offered by the Corporation, which is that, for a quantity not exceeding the maximum demand for 365 hours per annum, the charge is 6d. per unit, and for all above this quantity 2d. per unit. The first method of paying off the standing charges is also offered, but the Corporation having introduced the Maximum Demand System and Maximum Demand Indicators, and wishing to do without the latter, have no alternative but to charge on the consumer's application. The charge is also slightly higher, being £6 15s. 5d. per k.w. of application. If all the consumers would agree to pay on their application, I have no doubt this charge would be nearer the figure I have stated, viz., £4 8s. per k.w. This system of charging is by no means new. Dr. Hopkinson drew attention to the matter in his classical paper read before the Institution of Junior Engineers, and clearly proved that "the cost of supplying electricity cannot be correctly defined at so much per unit, unless the rate of supplying that unit is also stated, and showed that the cost depends much more on the greatest rate at which the electricity has to be supplied than it does on the amount actually used. He moreover urged that it was both morally unjust and commercially inexpedient to charge a uniform rate *for a manufactured* commodity which, in one case, *might obviously* require ten times as much plant for

manufacturing as it would in another, owing to its having possibly to be supplied at ten times as great a rate." Mr. Arthur Wright was the first, I believe, to make practical use of this idea. In a return made by the Town Clerk of Gloucester last year, it appears that, out of 60 local authorities owning electricity supplies, forty use Wright's indicator and system of charging. In some cases motive power is quoted at a lower uniform rate, but the sole reason for this reduction is that the chances are that motive power will be used for some four or five hours per day throughout the whole year, but it seems unfair that a similar benefit should not be extended to long-hour consumers using current for lighting purposes, seeing that the cost of generation is the same whether the energy be used for power or lighting. The third method offered by the Glasgow Corporation is a Uniform Rate, and is as follows for the 200-volt supply. Current is supplied at a uniform rate of 2d. per unit provided the customer agrees to pay for a quantity corresponding to his maximum demand for the equivalent of five hours per day for 365 days in the year, *i.e.*, for 1,825 hours per annum. Under this method the applicant's standing charges are spread over at least 1,825 hours, and, on a charge of £6 4s., therefore, only amount to 0·8d., that is supposing his consumption exactly equals 1,825 hours of maximum demand. The actual average works costs per unit are 1·28d. for an average of 2½ hours per day consumpt on the whole station; so that it is not underselling the current if a consumer using it for five hours per day per annum gets it at 2d. It may be asked why it is necessary to adopt this method of charging for a supply of electricity when gas is supplied at a uniform rate. I think we only need to apply the Maximum Demand system to a gas supply to see the reason and the necessity for this, especially at the commencement of an electrical installation, for later on it may be possible to level things down a little and to make the system of charging more uniform. I take the Gas Accounts of the Glasgow Corporation Gas Department for last year from the *Gas World* Year Book. The capital in Works and Plant is £1,315,680. These works and plant I roughly calculate supply what it would take 112,000 k.w. of electric plant to supply. The cost per equivalent of a k.w. is therefore only £11 15s. as against the electricity plant £55.

The amount written off for depreciation was £35,716, or 2·7 per cent. Interest and sinking fund account for £69,933, or 3·1 per cent. This makes a total of 5·8 per cent., or an annual cost of 13s. 7d. for gas plant as against the annual cost of £7 5s. 9d. per k.w. for electrical plant. If the management expenses are added to this, the sum of 13s. 7d. is raised approximately to 14s. 6d., which, if divided into 365 equal payments, is less than ½d. The actual costs of making gas are given as—

Coal, etc.	... ...	1s. 8d. per 1,000 cubic feet.
Distribution, etc.	...	0s. 2¼d. " " "
Sundry charges	...	0s. 1½d. " " "

and the gross cost of gas is 1s. 11¾d. per 1,000 cubic feet—say 2s.

The charge for gas on the Maximum Demand System would therefore be something like this: 2s. 0½d. for the first 365 hours of maximum demand, and 2s. for all used above that. You can therefore understand why a uniform charge of 2s. 2d. is adopted. I would like to give you one other set of figures in this connection.

	£
The capital of the Gas Department is	1,315,680
And the Revenue is	631,644
(or nearly 50 per cent. of the capital).	
The capital of the Electricity Department was, at 31st May last	322,000
And the Revenue was	44,141
(or only 13 per cent. of the capital).	

This also shows the difference between the two supplies. No doubt the capital of the Gas Department is very low, for the department has been in existence for thirty years, and has regularly written off large sums for depreciation, which go to reduce the capital. The Electricity Department will have a similar benefit. These figures must be taken as only approximately correct, as there are other items which enter into the gas accounts, such as the sale of residuals.

I now wish to consider briefly the question: In what direction are we to look for a reduction in our present price and a nearer approach to a uniform rate?

The first item on the capital cost sheet is Land and Buildings. This, for several reasons, should be at least

halved, making it £7. The cost per k.w. for plant would come down to something like £16. Accumulators will at least be quartered. Mains and cables should approach £33. (The result of an increased pressure of supply would have materially lowered this item had not the price of copper nearly doubled itself just as the 200- and 250-volt lamps were coming.) Meters will be increased and may be doubled. The other two items will at least be halved, and we hope in the course of time to have a capital cost per k.w. of—

	£	s.	d.			£	s.	d.
1. Land and Buildings... ...	7	0	0	...	1 per cent.	0	1	4
2. Machinery and Plant ...	16	0	0	...	7½ " "	1	4	0
3. Accumulators...	0	10	0	...	10 " "	0	1	0
4. Mains and Cables	33	0	0	...	2½ " "	0	16	6
5. Meters...	8	0	0	...	6 " "	0	9	6
6. Instruments	0	9	0	...	5 " "	0	0	5
7. Counting-house Furniture ...	0	1	0	...	5 " "	0	0	0½
	£65	0	0	per k.w.		£2	12	9½

Allowing the same rate of depreciation, the sum of £3 12s. is reduced to £2 12s. 9½d.; adding on, as before, 3 per cent., and 1 per cent. on a smaller capital, we have the standing charge of £7 5s. 9d. reduced to £5 6s. 1d., and adding on management expenses the sum will not be more than £5 10s. This will have the effect of reducing the sum of £6 4s. per k.w. of maximum demand in my first figures to £3 17s. per k.w. The selling price per unit will no doubt be reduced too, but it will only be by decimals of a penny. Let us assume it will be reduced to 1¼d. per unit. On the Glasgow prices and methods of charging the figures then would be 3¾d. per unit for a quantity equal to 365 times the maximum demand, and 1¼d. per unit thereafter, or if every consumer would agree to it under the fixed charge method, £2 15s. per annum or 4s. 7d. per month per k.w. (*i.e.*, 1s. 8d. per annum per 8 c.p. lamp fixed) of application, plus 1¼d. per unit, or 1¾d. all round for a consumer using at the rate of five hours per day. Further, the depreciation written off from year to year, and the sinking fund, will go to reducing the capital, so that even these figures may be further reduced.

A uniform charge may be adopted before these prices are

realised, but it will undoubtedly require to be one in which consumers are classified according to their probable hours of lighting. Even then there will be cases where consumers should be charged higher or lower rates than those used for the bulk of the consumers. From a table made out by the Reason Manufacturing Company, classifying consumers of electric energy in Brighton, it is shown that in the case of shops, for instance, 6 per cent. of them use the light for under one hour and 6 per cent. use the light over four hours. The great majority use it between two and three hours. Such a method as this averaging would mean that, in Glasgow—

Shops would be charged	5d.
Private Houses	4d.
Hotels and Clubs	3d.
Public-houses	1½d.
Offices	6d.
Theatres	3½d.
Hospitals	2d.
Schools and Churches	5d.

The maximum-demand method undoubtedly gives a means of charging each consumer as nearly as possible the actual cost of supplying his energy, except in the case of one who does not use his supply for the equivalent of one hour per day. A uniform rate places the supply company in the position that they may be supplying one consumer at a dead loss, while they may be charging another consumer double the price he ought to pay. The differential rate, on the other hand, assesses consumers so as to yield an approximately equal rate of profit on each consumer. The Board of Trade allows a maximum price of 8d. per unit, and a minimum bill of £2 13s. 4d. per annum. The maximum price at present is 6d., and no minimum bill has so far been enforced.

The object of a municipal supply, it may be said, is that from Corporation ownership and management a general benefit may accrue. This is true, and the result is that all consumers are offered a supply of current on the same terms, irrespective of the part of the city in which the premises to be supplied may be situated, and at a rate that practically none of the consumers could in the end produce

it for themselves. In this connection I may say, however, that I recently heard of a house in London which was advertised to let "fitted with electric light and favourably situated near a feeding point of the company's mains." Further, by the combination of all classes of premises the effect is that, to meet the demand of the whole community, there is required to be put down only half the plant which would be necessary if each had an installation of its own. I will here call your attention to some curves (Fig. 1) I have drawn showing the cost of a one to twenty-four hour consumer in various cities, and to a curve showing the

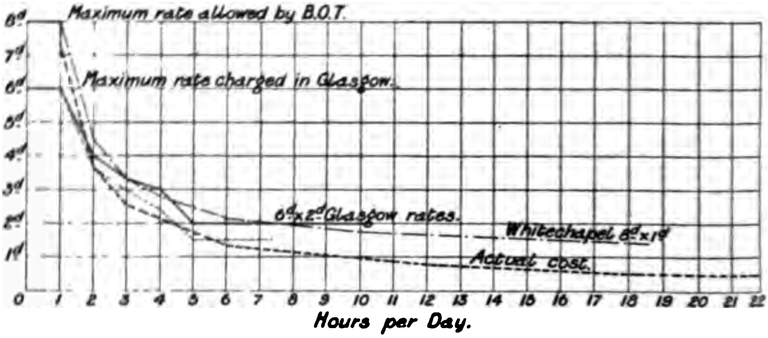


FIG. 1.

actual cost of such a supply. The thick dotted line shows the actual cost of a supply in Glasgow, and the other curves are for Glasgow charges of 6d. and 2d., and 6d. and 1½d.; Whitechapel, 8d. and 1d.; Bradford, 4½d., 2½d., and 1d. In Aberdeen the charges for lighting are 6d. per unit for the first 365 hours of maximum demand, and 3d. per unit thereafter; and for motive purposes, 4½d. and 1½d. Other municipalities under this system are—

Brighton	...	7d. for the first 365 hours and 1¼d. thereafter.
Bradford	...	4½d. for 3 hours, 2½d. for 4 hours, 1d. for 8 hours.
Manchester	...	5d., or £7 per annum per k.w., *plus* 1¼d. per unit.
Shoreditch	...	5d. for 730 hours and 2d. thereafter.
Stafford	...	7d. for the 1½ hours in winter and ½ hour in summer, and 3d. thereafter.

Edinburgh is a notable exception to all other cities. A niform rate is charged there of 3½d. per unit for lighting

and 1½ per unit for power, with discounts I believe. The success that has attended electric lighting in Edinburgh is no doubt partly due to the high price of gas, viz. 3s. 4d., as against Glasgow at 2s. 2d., and to the liberal use of electricity in street lighting. Not only has this raised the load factor of the station, *i.e.*, the ratio of the number of units generated to the number that could be generated if the greatest load remained on for 24 hours per day throughout the whole year—50 per cent. higher than we have in Glasgow, but it has been the means of their selling a greater number of the low-rate units, which are the units on which there is by far the greatest profit. Still it is probable that in Edinburgh there are consumers who should only be charged 1½d. per unit, and others 6d. per unit. In two supply stations meters registering at different rates have been used, the object being to charge the low rate all day long, and then sixpenny or standing charge units between the hours of sunset and sunrise. This, of course, tells hardly on the long-hour consumers, who use the power late in the night, and I cannot see why they should not be treated in the same way as the consumers who use it for long hours during the day. One other point you must all remember, that a supply in Glasgow, London, and Manchester is different from that in every other city, in so far as it has to meet a day-and-night demand on foggy days, and nothing tends more to give the supply a bad reputation than failing on such a day just when it is most required.

I have thus tried to give some idea of the basis upon which the more prevalent methods of charging for electricity are founded, how these methods work out, and how they are likely to be modified and developed in time to come. I can conceive of the objection being raised to this paper that it is hardly a legitimate and suitable one for such an institution as this, inasmuch as the subject with which it deals is not one with any direct or immediate bearing on any branch of engineering, electrical or otherwise. To this I reply that this subject is one of vital importance to the success and development of a public supply, and ought, therefore, to be of interest to all electrical contractors and engineers.

TABLE I.

CAPITAL AND STAND-BY CHARGES.

	Capital.	Depreciation	Per Annum.			Capital.			Per Annum.		
		Per cent.	£	s.	d.	£	s.	d.	£	s.	d.
(1) Land & Buildings	£14	1	0	2	0	7	0	0	0	1	4
(2) Machinery ...	£25	7½	1	17	6	16	0	0	1	4	0
(3) Accumulators ...	£2	10	0	4	0	0	10	0	0	1	0
(4) Mains	£44	2½	1	2	0	33	0	0	0	16	6
(5) Meters	£4	6	0	4	9	8	0	0	0	9	6
(6) Instruments ...	8/-	5	0	0	11	0	9	0	0	0	5
(7) Counting - House	2/-	5	0	0	1	0	1	0	0	0	0½
	£90		3	12	0	65	0	0	2	12	9½
3·1 % Interest ...	...	...	2	15	9	...			2	0	3½
1 % Sinking Fund ...	...	...	0	18	0	...			0	13	0
			7	5	9	...			5	6	1
Management Expenses	...	...	1	10	3	...			0	3	11
Total	...	...	8	16	0	...			5	10	0

TABLE II.

	Capital, per Equivalent in K.W.			Stand-by Charges per Equivalent in K.W.			Cost of Material used divided by the Maximum Price.
	Per K.W. £	s.	d.	£	s.	d.	
Gas	11	15	0	0	14	6	80 per cent.
Electricity	90	0	0	8	16	0	21 " "

TABLE III.

DISTRIBUTION OF REVENUE.

	Gas.	Percentage to Revenue.	Electricity.	Percentage to Revenue.
		Per Cent.		Per Cent.
Revenue	£631,644		£44,141	
Manufacturing Charges ...	£437,029	70	£13,141	30
Distribution Rates, Rents, Taxes and Management Expenses	£89,327	14	£10,872	24
Depreciation	£69,572	11	£7,521	17
Interest and Sinking Fund	£35,715	5	£12,607	29

Mr. H. A. MAVOR said that the Section was much indebted to Mr. Lackie for his paper, but that he could not agree with all the author's conclusions. In discussing the figures given in the paper for cost of supply, he (Mr. Mavor) pointed out that a large private consumer of electricity would probably produce current as cheaply as would the Corporation, and would save the expense arising from the distribution system inseparable from the public supply. He also pointed out that the amount standing at the debit of station charges for labour was very heavy indeed as compared with similar charges incurred by private consumers of electricity and producers of power, the discrepancy arising largely from the fact that electric lighting gives a very small load-factor as compared with that of ordinary manufacturing operations. He called attention to the fact that his company, Mavor & Coulson Ltd., introduced the maximum-demand system of charging in about the year 1888, and that they were, he thought, the originators of this method of charging for current. He called attention to the interesting fact that the average demand in relation to total lamps wired seemed to be about the same as he had found it in the days when public supply was originated in Glasgow. Mr. Mavor.

Mr. E. G. TIDD considered an allowance of 2½ per cent. for depreciation *plus* 1 per cent. to sinking fund for cables and accumulators was rather high. He thought that repairs to faults in the cables should be dealt with under the head of upkeep, and that a cable once properly laid and undamaged had practically no depreciation. He also applied similar remarks to the case of accumulators, and said that he believed makers were prepared to maintain the battery at a very much lower cost than Mr. Lackie put down. Mr. Tidd.

Mr. LACKIE, in his *reply*, thanked the speakers for the favourable criticisms on his paper. In reply to Mr. Mavor he said that, roughly speaking, a consumer having a maximum demand of less than 50 kilowatts Mr. Lackie.

Mr. Lackie.

and who used his power for less than 5 hours per day throughout the whole year, would find it cheaper to take his supply from the Corporation. Although a private installation saves the capital cost of mains, the Corporation have only to put down half the plant a consumer requires, so that the capital cost per consumer is half the figure stated. The rate of interest also which the Corporation pay for their money is about half that at which a private consumer would borrow it.

In reply to Mr. Tidd he would point out that depreciation all goes to reduction of capital and is for the benefit of the community in the end, though he did not think that 2½ per cent for depreciation on mains was excessive, even although repairs of mains were done at the expense of revenue. He also maintained that the maximum-demand indicator was a good healthy instrument, for, if the consumer knows that his bill depends more upon his maximum demand than upon the number of units used, he will watch that he does not waste light or current.

JOURNAL

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The Three Hundred and Forty-seventh Ordinary General Meeting of the Institution was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, on Thursday evening, May 3rd, 1900 — Professor SILVANUS P. THOMPSON, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on April 26th, 1900, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that they should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Osborne Pearston.	Edward John Wade.

Messrs. R. C. Quin and J. Hall were appointed scrutineers of the ballot.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. G. Johnson, J. C. Matthews, C. E. Wilson, and W. Golledge, to all of whom the thanks of the meeting were unanimously accorded.

The PRESIDENT: I have the pleasure to announce, on behalf of the Council, that, in accordance with our Articles of Association which permit us every year to elect one Honorary Member, the Council has elected as Honorary

Member for 1900 our past President, Mr. Joseph Wilson Swan, F.R.S., and that Mr. Swan has kindly informed us that he is willing to accept that nomination of Honorary Member.

I have also to announce that the Council has fixed the date of the annual Conversazione for Tuesday, June 26th.

THE CALCULATION OF DISTRIBUTING SYSTEMS OF ELECTRIC TRACTION UNDER BRITISH CONDITIONS.

By H. M. SAYERS, Associate-Member.

The design of electrical distributing systems in this kingdom has been practised hitherto almost exclusively for electric lighting purposes. The short daily duration of the heavy load and small annual load factor obtained in most cases induce economy in capital expenditure, and the current density at times of full load is restricted by considerations of pressure variation, rather than by losses in the conductors. The conditions of working electric tramway systems are so different that calculations of another order come in, and very materially affect the design of the conductors when highest total ecomony has to be studied. The principal special conditions are as follows :—

1. The high load factor—due to the fact that a large output is called for throughout the whole of the working hours, which are usually from 15 to 18 per day in the United Kingdom. There are daily "peaks" and seasonal peaks, but the hills and valleys are of much less extreme character than those observed on a lighting system.

2. The permissible variation of pressure is much greater. So far as the working of the line is concerned, the only limitation is that sufficient pressure be given at every point to enable the cars to keep schedule time. At the speeds allowed in this country, and with the motors usually fitted, a variation of 10 per cent. of the normal pressure causes no inconvenience.

3. The unsymmetrical arrangement of the two conductors, as between the outgoing or insulated positive conductor : and the return earthed negative conductor. In great majority of cases, the rails forming the negative

or return conductors are of such large section that no other conductors are needed on that side of the system whether for economical or pressure-regulating purposes—so far as the working of the line is concerned. But for the protection of other property, the extreme potential difference allowed to exist between different points on the rails is limited by the Board of Trade to 7 volts, and the proportion of current allowed to return through the general mass of the earth to an earth-plate at the generating station must not exceed 5 per cent. of the average load or 2 amperes per mile of line. Hence, on a tramway or railway using the rails as return conductor, while the positive conductor should be designed with regard to ordinary considerations of economy and efficiency (including the fact that practically the whole of the pressure-drop will occur on that side of the system); the negative conductor designed primarily to satisfy mechanical conditions in most cases accidentally happens to afford much better conductivity than the positive conductor, and yet its conductivity has in many cases to be supplemented in order to satisfy the regulations imposed by a benevolent Board of Trade. It will be seen below that the determination of these auxiliary return conductors can be arrived at by calculations similar to those controlling the choice of the positive conductors, but that some of the factors have different values, and that their load has to be estimated in a different way.

One effect of these special conditions is that the use of conductors designed for lowest total working cost is practicable in many electric traction systems. The well-known consideration that the total working cost of a conductor during any given time is the sum of two items, one being the value of the power wasted in it, and the other a percentage of its original cost at some annual rate, indicates at once that for a higher load factor a conductor should be worked at a lower rate of loss, or in other words at a lower current density. To determine the most economical current density in a given case, values are required for the following factors:—1. The money cost of the cable to be employed expressed in terms of the amount of copper in the cable, say the price in pounds of a ton of copper, insulated, sheathed and laid $= p$.

2. *The percentage* of the cost of the cable which must

be annually set aside to provide for interest, maintenance, and depreciation = R.

3. The average number of hours per day taken throughout a year that the cable will be under load = h.

4. The load factor of the cable during the time it will be under load. If the load will be steady, the value of this will be unity. If the load will vary in a known way, the load factor will be the mean square value of such variable load referred to a steady load of its maximum value as unity, and can be calculated from a prophetic load diagram, and in the case of such variable load the most economical current density given by the calculations will correspond to the square root of the mean square value of the current.

In what follows, this load factor will be taken as unity.

5. The cost of a Board of Trade unit generated and delivered to the conductor in pence = n.

From 3, 4, and 5 the cost per annum of a watt wasted in the conductor can be calculated, or inversely what number w of watts wasted in the cable will cost, say, £1 per annum, and the two quantities representing the total cost per annum reduced to a common measure.

In Perry's "Calculus for Engineers," page 55, the question of economy in electric conductors is used as an example in maxima and minima, and I have found the method there indicated convenient for practical use.

Professor Perry there shows that the waste in watts or ohmic loss, and the constant loss or interest loss, can both be simply expressed as functions of the resistance of a conductor, assuming a certain current and certain length, and that their value may be written: $y = C^2 r + \frac{t^2}{r} + b$.

Where $C^2 r$ is ohmic loss, $\frac{t^2}{r}$ is the interest item—expressed in watts, and b is a constant which depends upon factors not affected by the size of the cable laid.

In Appendix No. 1 Professor Perry's expression is worked out at length and the result shown that the most economical current density $\frac{C}{A} = \sqrt{\frac{R\, w\, p\, m \cdot 045}{100}}$, where C = amperes, a = cross-section of cable in square inches (so that $\frac{C}{a}$ = amperes per square inch) and m = tons of

copper in a mile length of one square inch section, R = annual rate per cent. for interest, etc.; w = the number of watts wasted continuously during working hours, which will cost £1 in a year's working, and p = the price in pounds of a ton of copper in the form of cable. ·045 is resistance in ohms of a mile of copper of one square inch cross-section, the weight m of which is 9·1 tons. In Appendix No. 2 an example is worked out numerically and tables are shown giving values obtained by taking figures within probable practical limits. The method of calculation here used is, of course, perfectly general, and applies equally to low-tension, high-tension, continuous and alternating currents, however fed to the conductors. The cost per ton of copper in cabled form will, of course, vary widely with the way the cable is to be used, the working pressure, and other conditions; for example, a triple twisted cable for three-phase currents will be much more costly per ton of copper than a concentric cable for continuous currents, working pressure and material being equal. It has also to be noted carefully that the value of the Board of Trade unit to be used is that of the unit delivered to the conductor system under consideration, and if the energy has to be transmitted or transformed before such delivery, the cost of generating the unit has to be "loaded" with the cost of such transmission or transformation, including the interest, maintenance, and depreciation cost of transmitting or transforming system. For example, the most economical density in a low-tension system fed from transformers is lower than in a low-tension system fed direct, assuming that the generating stations in the two cases supply energy at equal costs. It must also be recognised that power wasted (or used) in distribution costs as much as power used in the motors.

For cables of a given construction and for use under given conditions, it will generally be found that the average price per ton of copper taken from makers' prices through such narrow ranges of size as are usually employed on a given system is sufficiently accurate. Where a very wide range of size is called for it may be worth while to calculate separately for the larger and the smaller cables.

The question of systems of laying cables and the cost thereof is not considered here, as the choice of the methods

to be used depends much upon various local conditions, and the cost per mile is very little affected by the size of the conductor laid. It may be worth while to suggest, however, that the cost per ton of copper of a cable armoured for laying direct in the ground is higher than that of a similar cable sheathed for drawing into pipes or conduits, and as the allowance for depreciation and maintenance of pipes and conduits is a good deal lower than that for cable, economy may frequently be best studied by the use of a "drawing-in" system. The facilities for renewal and repairs and for replacing cables by others of larger size if required, are advantages not to be lightly ignored, and the conditions on electric traction systems enable these advantages to be utilised to a degree that does not obtain in some other services. The calculation of best sizes for track feeders is exactly that above described, but in most cases a higher value has to be taken for the wasted energy, *i.e.*, w in the equations is smaller. This leads to the use of a lower density in such cables or to a larger provision of copper for the current to be carried. The reason is that in most cases a "negative booster" has to be employed in connection with such a feeder, and the energy wasted has to be loaded with the loss in transforming, and the capital charges on the apparatus. The booster may be considered a part of the feeder, and as its size and the losses in it are proportional to its output, they are properly brought into the calculation by charging a higher price per unit delivered to the cable. Appendix No. 3 gives some examples of such calculations, and is also applicable to trolley feeders in which "boosters" are employed to keep up the voltage at the distant end.

Considering the figures given in the tables, it will be seen that the limiting distance due to loss of pressure in feeders designed on economical principles is reached at from two to three miles from the generating station. The density of the traffic does not affect this limit. The cost of energy does affect it, and in such a way that the lower this cost, the shorter is the range of economical distribution, because the economical density being higher, the limiting drop of voltage is the sooner reached. But it may be worth while in any particular case to use heavier conductors and so extend the working radius of a station, because the cheaper generation of power at that particular place more than compensates for increased distribution costs.

It may happen also that the use of heavier mains for the more distant parts of the system may prove to be cheaper than any other means of keeping the pressure up on those parts. It is a useful feature of the methods of calculation herein described that they indicate in a facile way the results of any departure from the theoretically best conductor sections, and so provide at least part of the data for determining the best system to adopt.

When the distribution radius much exceeds the distances above named, it will be obvious that the single station supplying direct to the feeder system becomes impracticable, and it is under these circumstances that an engineer is called upon to investigate thoroughly the alternatives, and estimate the total annual cost of working the lines by means of each of such alternatives. Only certain systems in practical use in the United Kingdom can be mentioned. They are—1. The multiplication of generating stations retaining the continuous-current low-tension system of generation. 2. The use of battery substations charged from a single generating station. 3. The use of a single generating station, generating polyphase currents at high pressure, and transforming substations placed at suitable points on the line, supplying low-tension continuous-current to the line feeders. The direct current for the lines near the station may or may not be generated by special continuous-current sets: when it is, separate consideration has to be given to such contiguous area, in calculating conductors and costs.

The second system above mentioned has but few examples, and reliable data are somewhat difficult to obtain. Its application would seem to be limited to cases where an infrequent service is given on distant lines; hence the feeders having to carry but a small average current, their size may be kept down, and the battery provides for the larger current needed by the cars. It will be obvious that the arrangements require to be carefully thought out in order to ensure the battery being properly charged, and always available during service hours. A very good example is that designed by the late Dr. John Hopkinson for the Leeds Tramway, and described in Professor Ernest Wilson's "Electrical Traction." It will be found that some complication is involved. Considering the present limited application and

the many questions of detail involved in calculating the working cost of such arrangement, the system cannot be discussed now, and is mentioned as a practical means of meeting the demand which may be sometimes made for working a long branch, the traffic on which only calls for a sparse service, or on which the traffic is relatively heavy for only a small portion of the working hours. The discussion will be narrowed down then to a comparison of the first and third alternative systems, involving a statement of the data which affect the choice and the calculations by which the working cost of each may be estimated with an exactness dependent upon the accuracy of the figures adopted. As some of these figures must themselves be estimated, the judgment and experience of the engineer are here very important factors.

It is quite clear that there are two broad questions to be decided in each case; first, What will be the total cost of producing a unit at the station or stations? and secondly, What will be the total cost of getting a unit to the car? The first question involves the charges on the capital cost of the station plant in addition to the working expenses, and the second question involves the efficiency of the distributing system as well as the capital charges upon it, as the cost of delivering a unit includes the energy wasted in its distribution. "Used in distribution" seems a more rational expression than "Wasted in distribution," but the latter phrase is so widely adopted that confusion might result from an attempt to reform.

It is obvious that by the multiplication of directly feeding generating stations *ad lib.* the loss in distribution as above defined may be reduced to any desired extent. On the other hand, with a system involving transformation there is some minimum loss which cannot be reduced, and which corresponds to the attainable efficiency of the transforming devices. Clearly, then, this minimum loss constitutes a handicap upon the multiphase high-tension system which must be overbalanced by other advantages in order to justify its adoption.

The reduction in the cost of generation of energy due to the employment of large units in one large station as against smaller units in a number of stations can only be estimated in advance by a complete study of local conditions guided

by experience and judgment. Cases arise, of course, where it is clear that a station at a particular place enjoys such a great advantage as regards cost of fuel, abundant available condensing water, and freedom from neighbours who may object to noise and vibration, that direct and indirect costs must be much lower than in any other available site. The greater economy in staff and in total value of plant and buildings to be obtained by generating at one station instead of several can be estimated very fairly. A more difficult item to estimate is the relative value of the land.

Whilst every case requires special study to determine what advantage in generating costs is attainable by the adoption of the single large station, a study of the distribution costs can be made on general principles, which will indicate what that saving must be in order to give the single station a balance of advantage.

The limit of continuous-current supply has been assumed to be the distance at which the drop in the trolley wire is 50 volts, *i.e.* 10 per cent. of the energy given to the cars. Assuming a uniform distribution of the cars, this means an average drop of 5 per cent. over the whole system. (Notice that if the system is one radiating from a large town, so that the cars are more dense near its centre, the average drop will be less. It can be calculated as closely as the service can be predicted.) The loss in track feeders will be less; probably 2½ per cent. will cover it in most cases.

This total loss of power in distribution, amounting to 7½ per cent. of that delivered to the cars, can be attained with generating stations spaced from 4 to 6 miles apart, *i.e.* delivering power, each for a radius of from 2 to 3 miles. As the interest item of distributing cost equals in value that of the loss of power item, it follows that distribution costs in such a system = 15 per cent. of the value of the power delivered to the car, and the total cost of 100 B.T.U. at the cars = that of generating 115 B.T.U. The plant has to be proportioned to produce 107½ per cent. of the energy delivered to the cars, as its normal full load.

In a multiphase transforming system, the overall efficiency cannot at present be taken at more than 80 per cent. Mr. Parshall has given figures from Dublin experience *showing* somewhat lower rates, but 80 per *cent. seems attainable.* Then the generating stations will

have to supply 125 units per 100 units delivered to the cars. The interest and operating costs of the distributing system cannot be calculated so simply in this case as in the former, as moving transforming devices calling for human attention are involved: but if the prices of those devices are known, and a proper rate of interest calculated to cover depreciation, the cost of attendance and sites can be got at pretty closely, and a price worked out per unit delivered to the mains which can be expressed as a percentage rate of loss of the energy delivered. If this is called N, the following expression shows at what proportionate cost the high-tension station must generate energy to counterbalance the larger distribution losses: $\frac{b}{a} = \frac{115}{125 + N}$ where b equals cost of production at the single h.t. and a=cost of production at the multiple l.t. stations. Unless $\frac{b}{a} < \frac{115}{125 + N}$ the low-tension multiple station system will give the lower working cost. For this calculation to be of any practical value, it is evident that the cost of production must be properly debited with all charges in each case. To make such an estimate for prospective stations with a near approach to accuracy is a task much more difficult than that of calculating conductors, but an incorrect decision as to the system to be preferred in a given case is not probable if experience and judgment are brought to bear on a careful investigation of the local conditions.

The value, N, above taken includes the interest item on both the high- and low-tension conductors. This value can be found as in the other case, and will as in that case be equal to the ohmic loss in each: but it must be noted that the cost of a watt is greater in the low-tension conductors owing to the transforming loss. The best density in the high-tension conductors is found exactly as in the case of direct supply, but the cost per ton of copper will be considerably higher in the case of the three-core high-tension cable, and hence the best density will be higher. The interest and operating costs of the transformers must be carefully considered, proper allowance being made for the necessary spare plant and margin of power necessary.

If these costs come to d pence per unit, the condition of advantage for the high-tension system is

$$\frac{b+d}{a} < \frac{115}{125+p}$$

where p is the percentage value of the losses in the high-tension conductors. This will usually be small, not over 5 per cent., and taking this value we get

$$\frac{b+d}{a} < \frac{115}{130};$$

so that for equal costs under the two systems

$$b = \cdot 885a - d;$$

or in words, the cost of generation at the single high-tension station must be less than 88½ per cent. of the cost at the low-tension stations by the cost per unit of interest, attention, and stores due to the transformers. If $b < \cdot 885\, a - d$, the difference is the saving per unit to be made by the high-tension system; if $b > \cdot 885\, a - d$, the difference is the advantage for the low-tension system.

Using correct data to suit the case, a very good judgment can be arrived at as to the most economical system to be adopted, and it is suggested with much confidence that such calculation is a safer guide than a general statement that for a traction station of over so many thousand horse-power this or that system is the only commercial one. It seems to be overlooked sometimes that the cost per unit at the car, and not at the switchboard, is the commercial criterion, and that to attain a lower figure at the car the cost of the unit at the switchboard must be very considerably lower in the case of any system using moving transformers than in alternative arrangements.

The choice of a site for a generating station may greatly affect the generation costs, and as these materially influence the design of the distributing system, the importance of careful choice of site or sites is very great, and in any contemplated electric traction system this should be one of the earliest matters submitted to and decided by the engineer. Whenever possible, eligible sites for compulsory purchase should be scheduled in the order authorising the line. The points affecting the choice are foreign to the subject now discussed and a certain cost per unit at the switchboard will

be herein assumed, the sole subject considered being the delivery of the power to the cars at minimum cost under the conditions imposed. The economical use of the power on the cars is also foreign to this discussion, but it cannot be seriously contended that waste on the car excuses avoidable waste in the distributing plant. The consideration of a particular case will best illustrate the application of the foregoing principles. Diagram A is a scale plan of a tramway system, all single lines with turnouts. The proposed service results in a distribution of cars as marked in figures along each section of the line. The total number of cars is 57. The average current taken by each car is reckoned at 15 amperes. Hence the average power demanded at the cars will be

$$\frac{57 \times 15 \times 500}{1000} = 427{\cdot}5 \text{ k.w.}$$

At T is a site available for a power-house. The extremes as regards distance from T are A 7·1 miles west, H 5·2 miles east, and L 7 miles south-west of T. There is, however, a shorter route from T to J than by the tramway, and this route being available for a feeder cable reduces the distance T L to about 4·35 miles, and facilitates feeding at J, which it will be seen is an important centre. In natural order one should first consider the use of T as sole generating station for the whole system, find the most economical current density, and see whether the drop permits of low-tension generation and direct feeding (Diagram B).

For the purpose of this example the following figures are used :—

Annual charges on cost of cable for interest and depreciation, 7 per cent. or $R = 7$.

Annual hours of use, say $15 \times 365 = 5{,}475$.

Cost of energy per B.O.T unit at switchboard $n = {\cdot}75$d.

Tons of copper per mile run of 1 square inch cross-section $= m = 9{\cdot}1$.

Cost of insulated cable per ton of copper $p = £151$.

Watts continuously lost worth £1 per annum $= w = \frac{240}{5{\cdot}475} \times {\cdot}75 = 58{\cdot}45$.

Then by formula given in Appendix No. 1 we have—

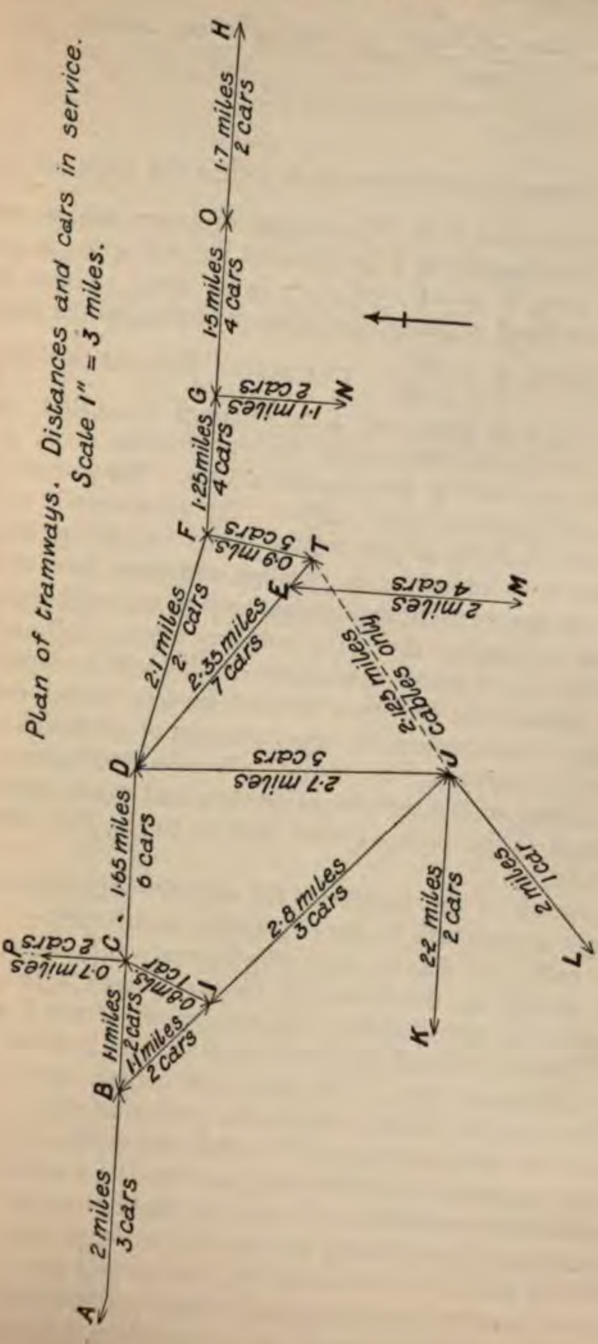

Plan of tramways. Distances and cars in service.
Scale 1" = 3 miles.
A
2 miles
3 cars
B
1.1 miles
2 cars
1.1 miles
2 cars
C
0.7 miles
2 cars
P
0.8 mls.
1 car
I
1.65 miles
6 cars
D
2.8 miles
3 cars
2.7 miles
5 cars
J
2.2 miles
2 cars
K
2 miles
1 car
L
2.1 miles
2 cars
2.35 miles
7 cars
E
2 miles
4 cars
M
2.125 miles
cables only
T
0.9 mls.
5 cars
F
1.25 miles
4 cars
G
1.1 miles
2 cars
N
1.5 miles
4 cars
O
1.7 miles
2 cars
H

DIAGRAM A.

$$t^2 = \frac{R.w.p.m. \cdot 045}{100} = \frac{7 \times 58 \cdot 45 \times \cdot 045 \times 9 \cdot 1}{100}$$
$$= 251 \text{ or } t = 15 \cdot 8\ ;$$

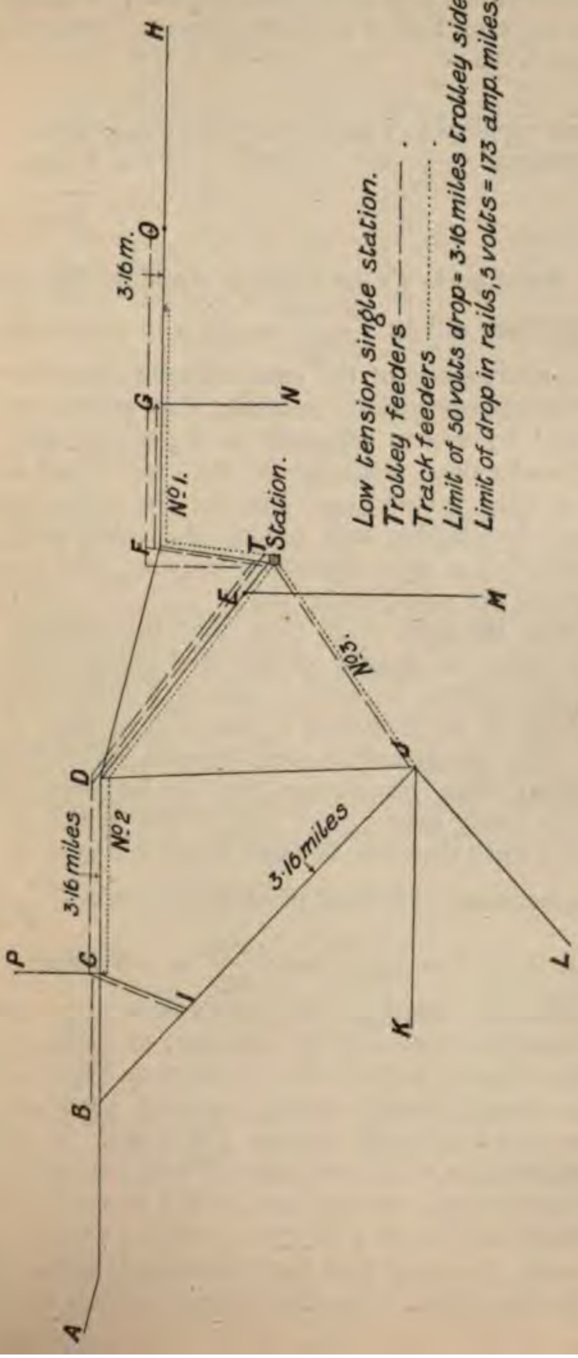
say—

$\frac{t}{\cdot 045} = 352$ amperes per square inch is thus the most economical density in this case. The voltage drop per mile is 15·8.

Hence the drop from T to A would be $15 \cdot 8 \times 7 \cdot 1 = 112$ volts, and from T to H $15 \cdot 8 \times 5 \cdot 2 = 82$ volts. These are too great for good working, and taking 50 volts as the limit, the distance limit is $\frac{50}{15 \cdot 8} = 3 \cdot 16$ miles. Beyond this limit there are 15 cars west and 3 cars east of T, so that two-thirds of the load come inside the permissible drop, and should be supplied by directly-fed cables. The remainder should be fed by "boosted" cables. No allowance is made for the conductivity of the trolley wires excepting where they suffice without cables in parallel, and there two No. 0 wires of ·162 square inches combined section are reckoned on. It is found in practice that in a tramway system calling for several feeders it is better to work the trolley wire in separate sections, each being fed by a distinct feeder. This results in the rapid localisation of short circuits of all kinds and minimises disturbance to traffic. It also facilitates the proper loading of the individual feeders and gives valuable information to the power-house staff as to the distribution of the load.

The losses in the feeders to the directly-fed portions of the sample system will be approximately as follows :—

The cable T J has to carry 98 amperes 2·125 miles; the average length on the branches beyond J over which the power will be distributed is, say, 1 mile total from T 3·125 miles. The branches J D and J I will only be fed *vid* J to points equidistant from T by the other routes, and on all these branches the trolley wires suffice without cable. The remainder of the current from T within the area is supplied by cables accompanying the line, and for the purposes of this approximate calculation it may be taken that the load is symmetrical along them, so that the average load may be taken as half the total and the loss as that due to half the current carried the extreme distance. (Obviously the loss may be calculated much more minutely than this for



Low tension single station.
Trolley feeders
Track feeders
Limit of 50 volts drop = 3·16 miles trolley side.
Limit of drop in rails, 5 volts = 173 amp. miles.
Station.
No. 1.
No. 2
No. 3.
3·16 m.
3·16 miles
3·16 miles
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
T

DIAGRAM B.

any given distribution of cars, gradients, etc.) The current being 532 amperes, half of it is 266 amperes. Then we get total loss in watts—

For current supplied to J	98 ×	3·125 ×	15·8 =	4,820
And the balance	266 ×	3·16 ×	15·8 =	13,300
				18·12 k.w.

As 58·45 watts cost £1 in a year's working, the money cost of this loss will be $\frac{18\ 120}{58{\cdot}45}$ = £310 in round figures, and as the interest cost of the cables should equal the total cost of distribution (strictly speaking that portion of the cost affected by system adopted) to the trolley wire, the total cost under these heads for the lines considered would amount to £620 per annum. But the use of the trolley wire where practicable will reduce the cable cost and interest item below this theoretical amount, and a table follows giving the actual feeder cost.

Inspecting the plan, it is clear that the junction I is about the centre of gravity of the load beyond the 3·16 miles on the western sections. This is 5 miles from T, and the load to be delivered is that for 15 cars = 225 amperes. The energy lost in these boosted feeders is more costly, having been transformed by the boosters, whose efficiency is rarely over 75 per cent. The value of the boosted unit must therefore be taken at ·75 × 1·33 = 1d., the value of w becomes 44 instead of 58·45, and $t^2 = \frac{251 \times 44}{58{\cdot}45}$ = 189 nearly, or t = 13·75 and $\frac{13{\cdot}75}{{\cdot}045}$ = 306 amperes per square inch as best density. Drop per mile is 13·75 volts.

The boosters would only be necessary to make up the drop in the lengths beyond the 50-volt drop limit, so that this lower density should, strictly speaking, apply only to the excess of cable length beyond 3·16 miles. It will be better, obviously, to use a conductor of uniform section to give the same drop. In the case of the western section then the drop will be 50 + (13·75 × 1·84) = 75·3 or 15·06 volts per mile, showing that the refinement makes little fference in this case. On the eastern section the drop

will be $50 + (13{\cdot}75 \times 1{\cdot}16) = 65{\cdot}95$, say 66 volts, or 15·3 per mile.

The losses will thus be :—

$$\begin{array}{llcrl} \text{Western} & 75{\cdot}3 & \times & 225 = & 16{,}942 \text{ watts.} \\ \text{Eastern} & 66 & \times & 45 = & \underline{2{,}970} \quad ,, \\ & & & & 19{,}912 \end{array}$$

Of this 20 k.w., $270 \times 50 = 13{,}500$ unboosted cost £1 per 58·45, and 6,500 cost £1 per 44, so that the total annual cost of the loss in these feeders will be :—

$$\frac{13{\cdot}500}{58{\cdot}45} = £231 \text{ nearly}$$
$$\frac{6{\cdot}500}{44} = \underline{\quad 148} \quad ,,$$
$$£379 \quad ,,$$

The interest on the mains will be somewhat less, owing to the use of trolley wire on the more lightly loaded branches. To this has to be added an annual charge representing interest, mainteanance and running cost of "boosters" to give an output of 6·5 k.w. With spare plant 10 k.w. might be provided, and would probably cost £20 per k.w., say £200. Fifteen per cent. per annum is a proper charge for interest and running expenses on such plant, so that this item would be £30 per annum.

The following is a schedule of feeders on the trolley side, wherever needed to supplement the trolley wires :—

DIRECT FEEDERS.

Line.	Length, Miles.	Amperes.	Section Cu. sq. in.	Tons, Cu.	Value.
T J	2·125	98	·277	5·37	£817
T E	·35	247	·700	2.23	337
E D	2·00	165 mean	·470	8·55	1,290
T F	·9	187 ,,	·531	4·35	655
F G	1·25	120 ,,	·342	3·56	538
	6·625			24·06	£3,637

BOOSTED FEEDERS.

[illegible]	[illegible]	[illegible]	[illegible]	Total Cu.	Value
[illegible]	[illegible]	225	·472	25·0	£3,775
[illegible]	[illegible]	60	·179	·15	23
[illegible]	[illegible]	75	·224	·22	33
[illegible]	[illegible]	45	·134	4·63	[illegible]
	[illegible]			30·00	£4,530

Total, £8,167.

The cost of distribution on the trolley side is thus :—

Loss in direct feeders, 18·12 k.w., worth annually ...	£310
Interest on cables in ditto, 7 per cent. £3,637 ...	255
Loss in boosted feeders { 13·5 k.w., worth £231 / 6·5 „ „ £148 }	379
Interest on cables in ditto, 7 per cent., £4,530 ...	317
Annual charges on boosters	30
	£1,291

This works out per unit delivered to the cars :—

$$\frac{1,291 \times 240}{427\cdot5 \times 5,475} = \frac{309\cdot840}{2,340,000} = \cdot133\text{d.};$$

making total cost ·883d., disregarding losses in the return conductors. But the regulation as to P.D. in rails forbids such disregard, and their effect must now be considered.

Assume that the track is single and laid with 90-lb. rails, or 180 lbs. rail per yard of track. Assuming the resistance of the rail to be 11 times that of copper of equal section, and that joints add 5 per cent. to that resistance, a mile of bonded track will have a resistance of ·0289 ohm. The interesting paper read by Mr. Parshall before the Institution on April 28th, 1898, will be familiar to all concerned in this question, as it shows by examples how the chemical composition of rails, kind of bonding, and number of joints per mile have to be taken into account. Naturally the mechanical

use of the rails takes precedence of their electrical functions, and hence the electrical engineer has to be thankful for what he can get. The resistance of the return as laid is usually lower than that of the rails alone, some conduction being afforded by the earth. The amount of this varies very much. Mr. Parshall has found an instance in which only two-thirds of the current returned by the rails. Weather affects it. In one case within the writer's knowledge wet weather reduces the voltage drop, and also the stray current, evidently increasing the conductivity of the non-metallic parts of the track.

But as this earth shunting of the rails cannot be foretold, the safe course is to take the resistance of the uninsulated return as that of the rails alone. To allow for possible increase of service, abnormally busy days, and bunching of cars, the limit calculated on should be, say, 5 volts, not the whole 7 volts allowed in the Board of Trade regulations. The integrated product of amperes into miles to give this drop will thus be $\frac{5}{\cdot 0289} = 173$ ampere miles. Mr. Trotter's paper of April, 1898, gives a neat and simple graphic method of showing the drop under given conditions. It can be easily applied along any section of line with a uniform service. For such a case as that under consideration, with varying services along different sections and junctions, an arithmetical process seems a little simpler. The arithmetical process is as follows :—Starting from the station, sum the product of amperes into miles until this product equals the constant corresponding to the limiting drop—*e.g.*, 173 for the case here assumed. It is at once clear that all current from cars beyond this point has to return by track feeders.

From this point start the integration afresh, and go on until the constant is again reached. At this second point the rails should be at earth potential. Recommence the summation from this second point and go on again to the constant. Then all the current due to cars between the first and third points should return to the station by a track feeder connected at the second point, and so on in succession, the even points marking feeder connections kept at earth potential, the odd points marking points of maximum P.D. above earth in the rail. This calculation applies equally to feeding points in transforming systems, so far as such points

depend upon the drop in the return. It will be clear that the direction of the current must be from odd points to even points. When the terminus of a route does not correspond with an odd-numbered point, integrate the ampere miles from the last odd point forwards, and from the terminus backwards, and the point on the line where these sums are equal is the last feeding point, the potential of which may be above that of the earth by the amount corresponding to the defect in the ampere miles from the constant. This means, of course, a somewhat lighter feeder, but the difference is usually insignificant as regards economy.

Obviously, the calculations above described will only give correct results for the distribution of traffic and current assumed. Such assumptions can only approximate to average working conditions, and it is only prudent to allow a considerable margin on the upper side in assuming the traffic, for growth and other obvious possibilities. Again, the feeding points so found may not be the best practically. It would be better, for example, to feed the track at a junction, connecting the feeder to all the diverging roads, than at a near point indicated by calculation, which would result in excessive current density in the rails of one road. Such excessive density may damage rails and possibly cause local damage to adjacent pipes.

The best density of current for track feeders is determined exactly as for trolley feeders, giving the wasted watts their proper rate as "boosted watts." Unboosted track feeders are of no commercial value, as Mr. Parshall distinctly showed in the paper before referred to. In our example, the density for boosted feeders has already been shown to be 306 amperes per square inch, giving a drop of 13·75 volts per mile run. From these figures the feeder sections and losses, and sizes of boosters, can be readily applied to suit the feeding points found in the manner above explained. The detailed calculation for track feeders is given in Appendix No. 4, and all track feeders needed on this system are shown in diagram B. The list of them is as follows :—

No.	Route.	Length.	Current.	Sections. sq. in.	Tons Cu.	Value.	Drop.	Loss in Watts.
1	T E'wards	2·97	120	·39	10·5	£1,585	41·6	5,000
2	T W'wards	4·00	273	·89	32·3	4,877	60·24	17,000
3	T to J	2·15	127·5	·415	8·1	1,223	32·4	4,200
		9·12			50·9	£7,685		26,200

Boosters to a total capacity of, say, 36 k.w. would be needed, costing, say £15 per k.w. or £540. Annual charges at 15 per cent. on these amount to £81. As before, the interest on the mains is rather less than the cost of power, the assistance of the rails coming in to reduce it. We then get on the track side :—

Loss in feeders, 26·2 k.w., worth annually ...	£600
Interest on cables, 7 per cent. on £7,685 ...	538
Charges on boosters	81
Total	£1,219

Adding this to the cost on trolley side, £1,291, we get a total of £2,510.

This equals ·266d. per unit delivered to the cars, making its cost there 1·016d.; and the total annual generating and distribution costs, as far as here considered, £9,936.

There will be 25·645 miles of cable laid in 12·025 miles of trenching, weighing 104·15 tons, to the value of £15,853, in addition to the cost of laying them. Boosters will cost £740.

The electrical efficiency of the whole system will be about $\frac{427{\cdot}5}{499} = 86$ per cent. or a trifle higher. These figures show very strongly that a single low-tension station for this system is very expensive in first cost of distribution plant, cables alone costing £32 per k.w. capacity. The regulation as to potential drop in rails puts direct supply out of court as soon as the distances and traffic exceed certain moderate figures. It seems, however, that a modification in track construction, using continuous girder supports under the rails and dispensing with concrete and setts between them, should be a logical consequence of electrical traction.

and that the conductivity of the track might thus be largely increased and bonding made much more permanent without much increase in construction costs. The difficulty now experienced at the joints of tram rails should disappear, and the life of the road be greatly increased. For electric traction purposes the granite between the rails is entirely unnecessary. Municipal tramway engineers might give this a trial; companies cannot do so in the present state of the law.

MULTIPLE STATIONS.

The first alternative to this costly single-station system is the provision of a second generating station (Diagram C), still using low-tension plant and distribution, and retaining T as one station, as the plan indicates that T is fairly well placed for the eastern part of the system. The junction I appears to be a good position, consequently the second station is assumed to be at that point. The arrangements east of T will remain unaltered. On the west, the two stations ought to supply power up to equidistant points measured along the tracks. The cross-country conductor T J will not be needed, and though useful for enabling one station to assist the other in case of breakdown (a valuable advantage of multiplicity of stations), it will not be further considered here.

The equidistant point on the route T D C I is ·1 mile west of D, and on the route T D J I it is 1·68 miles south of D. The western station I will then supply all the cars between C and D and two out of the five between D and J; its load will then be 24 cars or 360 amperes, leaving T to provide for 33 cars or 495 amperes. The cost of generating and the most economical current density are taken at the same rates as for the single station.

T has to supply westward the current for 14 cars, or 210 amperes as follows:—

60	amperes	for branch	E M,	average	distance	1·35 miles.
105	"	"	T D,	"	"	1·17 "
45	"	"	D J,	"	"	3·20 "

The two cars on branch F D are taken as before, as supplied *viâ* F.

At the voltage drop of 15·8 per mile the total watts lost come to 5,500. East of T they are as before, 8,250 un-

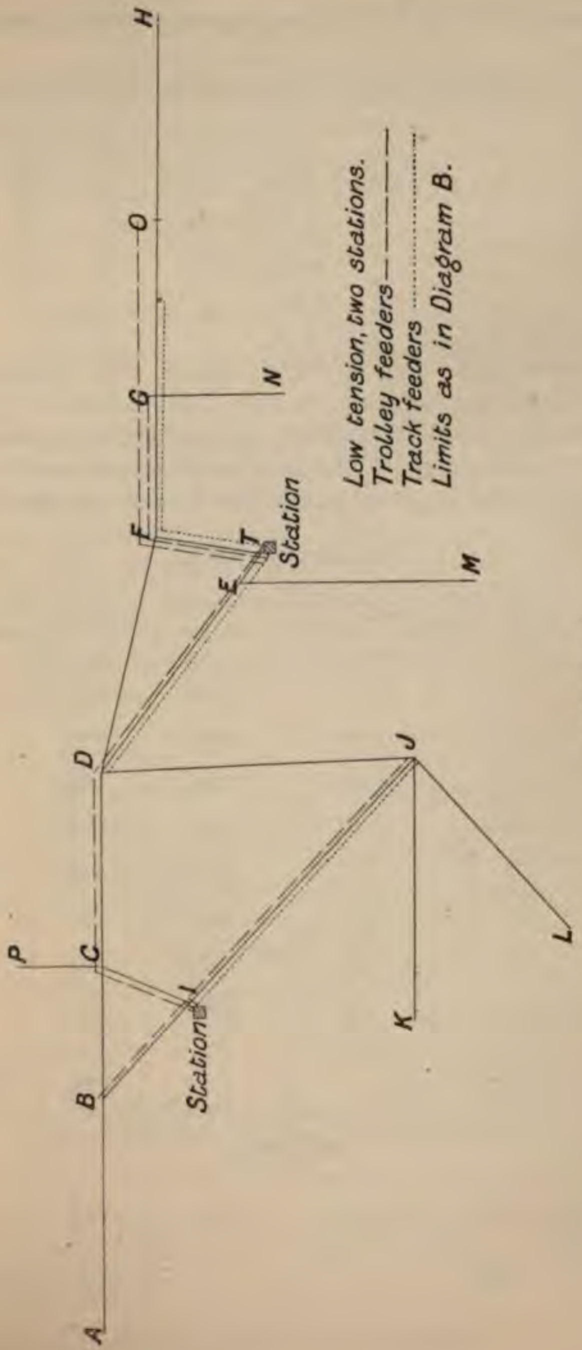

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
T
Station
Station
Low tension, two stations.
Trolley feeders
Track feeders
Limits as in Diagram B.

DIAGRAM C.

boosted, 720 boosted. I has to supply 360 amperes as follows :—

30 amperes to	branch	D J,	average distance	3·3	miles.
45 „	„	I J,	„ „	1·4	„
30 „	„	J K,	„ „	3·9	„
15 „	„	J L,	„ „	3·8	„
90 „	„	C D,	„ „	1·6	„
30 „	„	C P,	„ „	·8	„
30 „	„	I C B,	„ „	1·35	„
45 „	„	I B C,	„ „	·7	„
45 „	„	A B,	„ „	2·1	„

The total watts lost come to 10,602. No provision is made in this for boosting, as only a little current is carried beyond the 50-volt. drop limit, and under the circumstances that drop is unlikely to be exceeded in actual work.

The copper sections, weights, and values needed will be as follows :—

DIRECT FEEDERS.

Line.	Length. Miles.	Amperes Mean.	Section. Cu. sq. in.	Tons, Cu.	Value.
T F	·9	187·5	·531	4·35	£655
F G	1·25	120	·342	3·56	538
T E	·35	203	·579	1·84	278
E D	2·00	98	·277	5·02	758
I B	1·1	75	·213	2·13	323
I C	·9	142	·404	3·30	498
I J	2·8	98	·277	7·01	1,058
C D	1·65	45	·129	1·93	292
	10·95			29·14	£4,400

BOOSTED.

T O	3·8	45	·134	4·63	£699
	14·75			33·77	£5,099

Total 33·77 tons, value £5,099.

The cost of distribution on the trolley side is thus :—

Loss in direct feeders, 24·37 k.w., worth annually	£411
Loss in boosted feeders, ·72 k.w., worth annually	16
Annual charge on boosters	6
Interest on direct feeders, 7 per cent. £4,400 ...	308
Interest on boosted feeders, 7 per cent. £699 ...	49
Total	£796

This works out per unit delivered to the cars $\frac{£796}{2,340,000}$ = 0·81d., or total ·831d., disregarding losses in returns.

The track feeder east of T remains as before, and that west of T must tap the rails at D and carry 120 amperes, have a section of ·391 sq. in. with a drop of 35·5 volts, needing a booster of 4,260 watts. From I one feeder to J carrying 43 amperes section ·140 sq. in., drop 42·2 volts, will require a booster for 2,600 watts. No other will be needed, though a small addition to the service and load on the line between A and D would call for a feeder to B or C. The track feeders are then as follows :—

Line.	Miles.	Amperes.	Section, sq. in.	Tons Cu.	Value.	Drop	Loss watts
T E'wards	2·97	120	·39	10·5	£1,585	41·6	5,000
T W'wards	2.35	120	·39	8·33	1,258	35·5	4.260
I S.E ...	2·8	43	·14	3·55	536	42·2	1,815
	8·12			22·33	£3,379		11,075

Boosters to a capacity of, say, 18 k.w. will be needed, costing £270. The cost of distribution on track side will thus be :—

Loss in feeders, 11·075 k.w., worth annually	£252
Interest on cables, 7 per cent. on £3,379...	236
Charges on boosters, 15 per cent. on £270	41
	£529

and the total cost of distribution :—

Trolley side	£796
Track side	529
	£1,325

equal to ·135d. per unit, or a total of ·885d. The capital cost of the cables will be £8,478, their length 22·87 miles, laid in 13·85 miles of trenching, and the cost of boosters £310.

The cost of the cables amounts to £18 per k.w. full load output, and the efficiency about

$$\frac{427 \cdot 5}{468} = 91 \cdot 5 \text{ per cent.}$$

The annual costs of generation and distribution as above qualified will be £8,751, or £1,185 less than with the single station, and this sum is the margin out of which the extra working and capital charges due to the use of a second station have to be met. Unless such extra charges exceed the saving in distribution, the two-station system will be the more economical. A sound knowledge of the local conditions should enable a fair estimate to be made, but it is not susceptible of calculation on general principles. The incidental advantages of the multiple-station system should be carefully considered in each case, and if the calculable operating costs are about equal, those advantages should turn the scale in its favour.

Multiphase Distribution.

Assume one station, at T (Diagram D), generating plant to give 3-phase current at 2,500 volts. Using 3-wire mains, the current per conductor will be

$$\text{K.W.} \frac{1,000}{2,500} \times \sqrt{3} = (\text{K.W.} \cdot 23) \text{ amperes.}$$

The cables will be of the 3-core twisted or equivalent type, and on this account as well as the larger amount of insulating material needed, their cost per ton of copper will be higher. The depreciation will also be at a

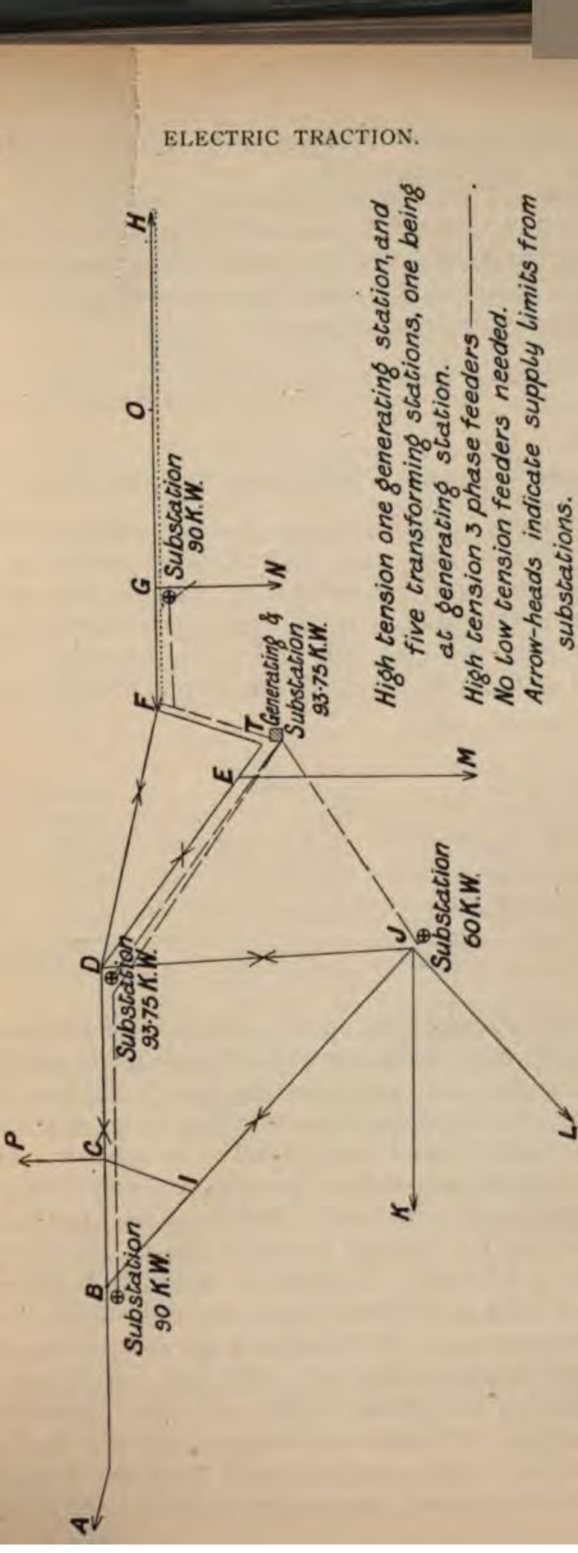

A
B
Substation
90 K.W.
C
P
I
K
D
Substation
93·75 K.W.
J
Substation
60 K.W.
L
E
M
T
Generating &
Substation
93·75 K.W.
F
G
Substation
90 K.W.
N
O
H
High tension one generating station, and
five transforming stations, one being
at generating station.
High tension 3 phase feeders ——.
No low tension feeders needed.
Arrow-heads indicate supply limits from
substations.

DIAGRAM D.

higher rate. First, because the scrap price will be a lower proportion of total value; and second, because high-tension cables certainly suffer more from faults than those under low tension. Therefore R is taken at 9 per cent. p at £208, the other values remaining as before—

$$t^2 = \frac{9 \times 58{\cdot}45 \times 208 \times {\cdot}045 \times 9{\cdot}1}{100} = 448 \text{ and } T = 21{\cdot}2,$$

the density $\frac{21{\cdot}2}{{\cdot}045} = 470$ *a* per square inch, and the drop per mile 21·2 volts. The loss in any 3-wire 3-phase conductor will be 3 C × 21·2 per mile, where C is the current as given above for the load transmitted, so that the loss per k.w. delivered to the cables will be ·69 × 21·2 = 14·62 watts per mile, or 1·46 per cent. per mile. Transformers will be required at G, T, D, J, and B, the output needed being as follows:—

From G	...	12 cars	...	90 k.w.
T	...	12·5	...	93·75
D	...	12·5	...	93·75
J	...	8·0	...	60·
B	...	12·0	...	90·
Total		57·0 cars	...	427·5 k.w.

These loads are allocated on the simple consideration that each transformer should supply half-way to its neighbour in each direction, and represent the energy delivered to the cars. Loss on the low-tension side has to be added to get the gross output, which may be taken at 450 k.w. Hence at four of the five sub-stations 100-k.w. sets, and at the other a 65 or 70-k.w. set would suit. But allowance must be made for spares and for unusual demands due to local pressure or bunching of traffic. Whether it would be better to put down two 100-k.w. or three 50-k.w. sets at the larger stations should in every case be determined on comparison of the cost of the different sized sets with their switch-gear, the probabilities of exceptional traffic, and other fairly obvious considerations. It might well happen that the two larger sets would cost little more to instal than the three small ones, and that the extra flexibility would be well worth the

cost. Assuming, however, that the three-set plan is adopted, it will be necessary to instal transformers to a total capacity of 705 k.w.

The high-tension feeders to these sub-stations will be as follows, assuming a full-load efficiency of transformation of 85 per cent., or rather a constant loss during operation at the rate of 15 per cent. of the rated capacity, and 2,500 volts pressure :—

Line.	Miles.	Amperes.	Sections. sq. in.	Tons Cu.	Value.	Loss in Watts.
T G	2·15	3 × 24·2	3 × ·051	2·98	£620	3,307
T D	2·35	3 × 25	3 × ·053	3·27	680	3,736
T J	2·15	3 × 16·1	3 × ·034	1·95	406	2,201
T B	5·25	3 × 24·2	3 × ·051	7·30	1,518	8,080
	11·90			15·50	£3,224	17,324

The loss in the transformers on the above assumption will be 15 per cent. × 470 = 70·5 k.w. With this disposition of sub-stations no track feeders are needed, and secondary trolley feeders can also be dispensed with, as the trolley wires of usual size will not drop more than 10 volts average all over the system, the worst point being H, where the drop will be 32 volts. The trolley wires leading east of G, from T to E, and B to C, will be somewhat heavily loaded, and for reliability of service it might be well to use some auxiliary feeders, or heavier trolley wires on these sections, but this will not be necessary for distribution efficiency.

The distribution losses will then be :—

In H.T. cables	17·3 k.w.
In transformers	70·5 „
In trolley wire	8·55 „
	96·35 k.w.

and the generating plant must be able to give out 524 k.w. Overall efficiency of the system being thus $\frac{427·5}{524}$ = 81 per *cent. nearly.*

This is a little higher than Mr. Parshall's figures for Dublin. No addition has been made to the cable losses for power factor being less than unity, and it appears probable on the rather scanty information obtainable in this country that full justice is done to current practice in the above result. To obtain the annual cost of this distribution, proper charges on the transformers, including attendance, have to be estimated. This again is not easy, for the prices of such plant are not readily obtainable, but for the present purpose market prices are not essential. There is good authority for the statement that for smaller sizes than 200 k.w. motor generators perform better than static transformers and rotary transformers, therefore motor generators are assumed in the following figures :—

	£
Motor generators to capacity of 705 k.w. at £15 per k.w. with switch-gear	10,575
Four sub-stations and sites at £80 each	320
	£10,895
Interest, depreciation and repairs, 12½ per cent. on £10,575 and 2½ per cent. on £320	1,329
Attention to each set, say 3s. per week or £7 16s. per annum, 15 sets	117
Oil, brushes, and sundries, say £2 10s. per annum, per set	37
Total per annum	£1,483

The distribution costs then work out as follows :—

	£
H.T. conductors, C^2R loss value $\frac{17,324}{58\cdot45}$	295
Interest on cables (cost £3,224)	290
Loss in transformers $\frac{70,500}{58\cdot45}$	1,205
Loss in trolley wire, 8,550 at 48·5 per £1	176
Interest and attention and stores on transformers	1,483
	£3,449

This sum amounts to ·352d. per unit delivered to the cars, making the cost of the power there 1·102d. per unit, or

£10,875 annually. This is ·217d. per unit, or £2,124 per annum in excess of the two-station direct supply, and £939 in excess of the one-station direct supply, as will be shown by the tabulated results below.

Obviously a high-tension station cannot generate at a lower cost per unit than a low-tension station on the same site, but the result of this investigation goes to show that if in the neighbourhood a site exists with such advantages that the cost per unit of the power generated there and delivered to T, or equal point, will be under ·53d., instead of ·75d., there will be an advantage in using the transformer system. In other words, this calculation shows what saving in generation costs is required to justify the use of a transformer system and a high-tension station.

The capital expenditure is not much reduced, as the total for cables and transformers amounts to £14,119, which lies between the costs of cables and boosters in the two low-tension systems discussed. There would be also a considerable saving in cable-laying expenses, due to the lighter cables and smaller number of ways needed. This point and the difference between the capital outlay in the stations are foreign to the present subject, but must of course be keenly studied in practical designing. It should, however, be noted that the load factor is of great importance, and that the assumed conditions are rather more favourable to a transforming system than the conditions usually found in practice, for the reason that the losses in transformers are largely independent of the load, and that sufficient transformer capacity must be kept in use to provide for the maximum demands during any given period. The device of dividing into small sets and putting them in as needed cannot be carried far for several reasons. Hence the losses are more nearly those due to the maximum than to the average load over any given period. Cable losses on the other hand vary with—and as the square of—the actual load, consequently a poor load factor tells much more against the efficiency of transformers than of cables.

The small proportion of the total losses due to the high-tension transmission indicates the small effect of distance on the overall efficiency, so that the radius within which the advantages of a specially favourable position for a generating station may be utilised is not severely limited. For lines on

which multiphase motors and the consequent increased number of overhead wires are impracticable. It is apparent that the advantages of this system are very great. Only [illegible] transformers being required, the overall efficiency can be kept high, and attendance at sub-station made next to nothing. This is hardly a live subject in this country yet, but the economies of distribution in such a system can be worked out on the same lines as here set forth when occasion shall arise and the regulations to be complied with shall be known.

The economical figures in the three schemes above worked out are here tabulated for comparison :—

	Low Tension.		High Tension.
	1 Station.	2 Stations.	1 Station.
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	£3,731	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	£8,788	[illegible]
[illegible]	[illegible]	22·87	[illegible]
[illegible]	[illegible]	13·85	6·55

APPENDIX No. I.

CALCULATION OF MOST ECONOMICAL CURRENT DENSITY.

Rate of ohmic loss = $C^2 r$ watts, where C = current in amperes and r = resistance in ohms.

Rate of interest and depreciation loss in £ sterling per annum. = $\frac{R}{100} p\,m$ + constant, where R = rate per cent. per annum of interest and depreciation; p = price in £ per ton of copper in the form of cable, m = tons of copper per mile of conductor of one

square inch cross-section; a = cross-section of conductor in square inches, so that $m\,a$ = tons of copper per mile; and the constant represents such costs of laying and other expenses as are practically dependent only upon the length of cable laid and independent of its size. To add these losses they must be equated for definite conditions of load and period of use. For this purpose, assume the period to be one year; the load to be steady and lasting for a certain fraction of every day $= \frac{h}{24}$. A certain cost per Board of Trade unit delivered to the conductor $= n$ pence.

Then £1 per annum is the cost of $\frac{240}{n}$ B of T units wasted per annum, and the rate of waste in watts which gives such a loss is $\frac{240{,}000}{h\,n \times 365}$, or $\frac{657 \cdot 5}{h\,n}$. Call this w. It is the number of watts which, wasted during all the working hours will cost £1 in a year.

Then $\frac{R}{100}\,w\,p\,m\,a$ is the interest cost of the cable expressed as a loss in watts during working hours, and the total rate of cost of distributing the current C through the cable is $y = C^2 r + \frac{R}{100}\,w\,p\,m\,a$.

The resistance of the conductor obviously affects the value of the two quantities making up the total loss in opposite ways, and the problem is to find the value of r which makes y least. Consider a cable of one mile in length. If the resistance of one mile of copper conductor of one square inch cross-section is $\cdot 045\,w$, then $a = \frac{\cdot 045}{r}$, and the second item of the total cost $= \frac{R\,w\,p\,m\,.045}{100\,r}$.

Since this has been equated to a rate of loss in watts it may be written

$$\frac{C_2{}^2 r^2}{r} = \frac{t^2}{r}, \text{ where } t = C_2 r,$$

C_2 being such a current as would produce the required loss in watts on traversing the resistance r. We then get

$$y = C^2 r + \frac{t^2}{r}, \text{ whence } \frac{d\,y}{d\,r} = C^2 - \frac{t^2}{r^2},$$

and this is a minimum when

$$C^2 = \frac{t^2}{r^2} \text{ or } r = \frac{t}{C}.$$

This is the Kelvin law, since when this is the case $C_2 = C$, and the two items of cost representing ohmic loss and interest are equal.

The most economical current density therefore is

$$\frac{C}{a} = \frac{t}{\cdot 045}, \text{ where } t = \sqrt{\frac{R\,w\,p\,m\,\cdot 045}{100}},$$

and the most economical rate of voltage drop is t volts per mile.

If the load is not steady but varies in a known way, then $C^2 =$ the mean square of the current in respect to time, and $C =$ the square root of that.

In the expression for t^2, $\frac{R\,p\,m}{100}$ is the annual cost of one mile of cable of one square inch copper section, *i.e.* of 9·1 tons copper weight.

Then $\frac{R\,p\,m\,w\cdot045}{100}$ may be written $\frac{\cdot41\,R\,p\,w}{100}$ or $\cdot0041\,R\,p\,w$

and the most economical current density written

$$\frac{C}{a} = \frac{t}{\cdot045} = \sqrt{\frac{\cdot0041\,R\,p\,w}{\cdot045}}$$

and a table of such densities for various values of the product $R\,p\,w$ can be readily formed.

APPENDIX No. II.

EXAMPLES AND TABLES OF MOST ECONCMICAL CURRENT DENSITY.

Symbols as in Appendix No. I.

$$\frac{C}{a} = \frac{t}{\cdot045} = \sqrt{\frac{\cdot0041\,R\,p\,w}{\cdot045}}$$

$R =$ percentage interest charge on cables.

$p =$ cost of one ton of copper in form of cable.

$w = \frac{657\cdot5}{h\,n}$, where $h =$ equivalent full load hours of use per day, and $n =$ cost in pence of one Board of Trade unit.

For example, let

$$\left.\begin{aligned} R &= 9 \\ p &= £200 \end{aligned}\right\} R\,p = 1800$$

$$\left.\begin{aligned} h &= 12 \\ n &= \cdot8\text{d.} \end{aligned}\right\} h\,n = 9\cdot6$$

$$w = \frac{657\cdot5}{9\cdot6} = 68\cdot49,$$

then $t^2 = 1800 \times 68\cdot49 \times \cdot0041 = 505\cdot4$,

and $t = 22\cdot5 =$ drop in volts per mile, whence :— $\frac{C}{a} = \frac{22\cdot5}{\cdot045} = 500$ amperes per square inch.

The equality of ohmic and interest losses is readily shown. One mile of cable of one square inch section will cost £200 × 9·1 = £1,820, and the interest on it at 9 per cent. will be £164, while the ohmic loss ll be 500 × 22·5 = 1,125 watts, worth also £164 per annum; to the rest £1 in each case.

Tables for varying values of R p and w are convenient, in the following form :—

w	t = drop per mile.	Best density.
	R p = 1,200.	
40	14	312
50	15·7	362
60	17·2	383
	R p = 1,500.	
40	15·7	362
50	17·6	392
60	19·2	427
	R p = 1,800.	
40	17·2	383
50	19·2	427
60	21·1	469

or a table giving values of t and best density for values of the product. R p w may be readily made and used.

APPENDIX No. III.

CALCULATIONS FOR "BOOSTED" FEEDERS.

The only special factor in these is the correct value of w. Such value should take into account the transformation loss in the booster, and the annual charges on that machine referred to its output.

If n is the cost of a Board of Trade unit at the main switchboard, and the efficiency of the booster at its average working load is $\frac{x}{100}$, the transformed units will cost $\frac{100}{x} n$ in energy alone.

Again, if the machine cost £a per annum in interest and depreciation, and £b per annum for attention and stores consumed per unit of average working output, these charges will add to the cost of the energy $\frac{(a+b)\,240}{365 \times h}$ in pence per B. of T. unit, the value of w will then be

$$w = \frac{240{,}000}{\left(365\,h \times n\,\frac{100}{x}\right) + 240\,(a+b)}$$

For example, if a booster cost £15 per k.w. output, and 12 per cent. is charged for interest, etc., and if it costs 10s. per annum for attention and stores, these costs amount to £2·3, or $a + b = 2·3$, then if the set is in service 15 hours per day

$$\frac{(a+b)\,240}{365h} = \frac{2·3 \times 240}{5475} = ·11 \text{ pence.}$$

With $n = \cdot 75$d. and efficiency 75 per cent., the cost per unit transformed becomes

$$(\cdot 75 \times 1\cdot 33) + \cdot 11 \quad = 1\cdot 11 \text{ pence.}$$

$$\text{and } w = \frac{240}{1\cdot 11 \times 5\cdot 475} = 39\cdot 5.$$

The values of w so found should be used in calculating the best density of current in the "boosted" feeders.

It must be noticed that where boosters are used, as on trolley feeders, to keep the drop within certain limits, the boosters have only to supply the difference between the permitted drop and that which occurs in the feeders, and the current density found as here explained is that which should prevail in the corresponding distance beyond the point at which an unboosted feeder will give the limiting drop. Hence the total drop in the boosted feeder should be the sum of the limit, and that in the length beyond at the density here found, and the actual section of the feeder should be such as to give that drop on the actual feeder length. Thus, if the limiting drop is 50 volts, and that is given by an unboosted feeder 3 miles in length; whilst a boosted feeder is 4½ miles long, and should drop 15 volts in the 1½ miles excess, the proper uniform density in the whole 4½ miles should be such as to give 65 volts drop. Unless supply is given much beyond the limiting drop distance, the decrease in current density as compared with that found for direct feeders will not be large. In track feeders, however, the "boosted" density is practically correct, as the permissible drop is always much exceeded.

The best density for secondary feeders supplied from transformers is found in the same way as for track feeders.

APPENDIX No. IV.

Calculation for Track Feeder, East of T.

Rail resistance, ·0289 w. per mile.
Drop allowed, 5 volts.
Amperes × miles constant for 5 volts = 173.
Current per car, 15 amperes. Cars passing in pairs.

From T Eastwards.

Cars.		Amp. miles.	Product.	Sum.
T to F, 5 cars, ·9 miles.	1st pair ...	... 30 ×	·3 = 9	
	2nd pair ...	... 30 ×	·6 = 18	
	1 at F ...	... 15 ×	·9 = 13·5	
	2 on line D F	... 30 ×	·9 = 27	67·5
F to G, 4 cars, 1·25 miles.	1st pair ...	... 30 ×	1·21 = 36·3	103·8
	2nd pair ...	... 30 ×	1·83 = 54·9	158·7
	2 on line N G	... 30 ×	2·15 = 64·5	223·2

As the sum is brought over the constant by the current flowing in at G from branch N G, G should be a point of change of direction. The product of amperes × miles on branch N G is $15 \times 1{\cdot}1 = 16{\cdot}5$ This added to the 158·7 at G = 175·2, a little over the limit. Hence the whole of the 30 amperes from branch N G should flow east, and the integral of ampere miles from G to feeding point should be $173 - 16{\cdot}5 = 156{\cdot}5$, to keep N at 5 volts.

Then from G Eastwards. Section G O, 4 cars.
1·5 miles long. Current flowing east 30 amperes from branch N G.

Cars.	Amp. miles.	Product.	Sum.
At G		16·5	
G to 1st pair ...	30 × ·375	= 11·25	27·75
1st pair to 2nd pair	60 × ·75	= 45·00	72·75
2nd pair to O ...	90 × ·375	= 33·75	106·50

H being terminus, and only 2 cars between H and O, it is obvious that feeding point should be west of O, so sum westwards from H.

	Cars.	Amp. miles.	Product.	Sum.
H to O 1·7 miles.	1st pair to O ...	30 × ·85	= 25·5	
	O to 2nd pair G O	30 × ·375	= 11·25	36·75
	2nd to 1st pair G O	60 × ·75	= 45·00	81·00

Feeding point will thus be between the 1st and 2nd pair of cars east of G. It should be exactly ·825 miles east of G. The product from this point will be 54·75 to the terminus H and to N, corresponding to 1·58 volts drop. Hence the feeding point may be 3·42 volts above earth.

The track feeder will have to carry back 120 amperes, and be 2,975 miles long. Section should be ·39 sq. in., and the drop in it will be $15{\cdot}06 \times 2{\cdot}975 = 45$ volts. But as its end may be 3·42 volts above earth, the booster will have to give only 41·58 volts, and have an output of $41{\cdot}58 \times 120 = 5{,}000$ watts say.

Track Feeder No. 2.

From T Westwards.

It is obvious to inspection that some current should return *viâ* D and some *viâ* J. The dividing points should be those at equal distance from T by each route.

On the branch D J this point is practically at the centre of its length, hence half the total current is taken as flowing each way.

On the circuit T D C I J T it is very close to the junction I. Hence the current returning by J will be half that on the branch D J, and the whole of that on branches from J to I, K and L respectively, making altogether $8{\cdot}5 \times 15 = 127{\cdot}5$ amperes, which gives at once the section of the track feeder from T to J. It also follows that the potentials of points D and J should be kept equal. Find feeding points, etc., as before.

T to D, 7 cars 2·35 miles. Branch C M, 4 cars = 60 amperes at ·35 miles from T.

Assume 1 car at *D, the other 6 in pairs at ·59, 1·18 and 1·77 miles respectively from T.*

Current Eastwards towards T.

Cars		Amp. miles.	Product.	Sum.
T to C	... ...	60 × ·35	= 21·00	
T to 1st pair	...	30 × ·59	= 17·70	38·7
T to 2nd pair	...	30 × 1·18	= 35·40	74·1
T to 3rd pair	...	30 × 1·77	= 53·10	127·2
T to D	... ...	15 × 2·35	= 35·25	162·45 = 4·7 V.
T to O, part current from branch D J		4·4 × 2·35	= 10·5	173

giving 5 volts at D.

Current Westwards from D.

D to C, 1·65 miles, 6 cars, passing at ·41, ·82, 1·23 miles from D, 33 amperes from branch D J also—

Cars.		Amp. miles.	Product.	Sum.
D to 1st pair	...	33 × ·41	= 13·53	
1st to 2nd pair	...	63 × ·41	= 25·83	
2nd to 3rd pair	...	93 × ·41	= 38·13	
3rd to C	... ...	123 × ·41	= 50·43	127·92 at C

Count back from A to find equal point.

A to B, 2 miles, 3 cars, assume 1 at A, 2 in middle.

Current Eastwards from A.

Cars.		Amp. miles.	Product.	Sum.
A to 1st pair	...	15 × 1	= 15	
1st pair to B	...	45 × 1	= 45	60

B to C, 1·1 miles, 2 cars, assume in middle, current of one car from branch B J. Continue summing from A.

Cars.		Amp. miles.	Product.	Sum.
B to middle	...	60 × ·55	= 33	
Middle to C	...	90 × ·55	= 49·5	142·5 at C

This indicates feeding-point a little west of C, but as 60 amperes more enter from branches north and south of C, and C is the meeting place of four tracks, it is clearly the proper place for the feeder to tap the rails. If this point be kept at earth potential, A, the point farthest from T will be at 4·1 volts above earth.

The feeder will be 4 miles long, have to carry 273 amperes back, have a section of ·89 sq. in., will drop 4 × 15·06 = 60·24 volts, and booster must give 273 × 60·24 = 16,445, say 17,000 watts.

Track Feeder No. 3.

Inspection of the diagram suffices to show that J must be the feeding point for this. The greatest drop thence will be on branch J K, 2·2 miles long with 2 cars. Assume one at K and one half way, then ampere es K J will be 41·25 or 1·2 volts. J must then not be more than 3·8 ove earth. This is lower than D, so that more than the half

current on line J D will return by the feeder *viâ* J. *Per contra* part of the current from branch I J will go *viâ* I C. The assumed distribution could be obtained by splitting the feeder at J, and connecting the branches at proper points on the three lines J L, J K, J I.

No practical advantage would result, as in working the load on each feeder is regulated to keep the pilot wire indications within proper limits, by control of the booster E.M.F., and it is quite certain that the actual load and its distribution will vary widely and rapidly in any given case from any assumed distribution, consequently in a network requiring a number of track feeders it is sufficient to ensure that they shall be provided of needful section and number to enable the P.D. on the rails to be kept within limit, and refined investigation of the current distribution is likely to be labour lost.

Hence No. 3 feeder may be safely taken as tapping rails at J. It will be 2·15 miles long, carry 127·5 amperes, have a section of ·415 sq. in., drop 32·4 volts, and require a booster to give $32 \cdot 4 \times 127 \cdot 5 = 4{,}130$, say 4,200 watts.

The PRESIDENT: The subject of the paper is now open for discussion.

Professor A. JAMIESON: I am sorry that I only got a copy of Mr. Sayers' paper upon entering this room, and therefore, feel that I cannot thoroughly discuss it at so short a notice. I certainly think that it contains a great deal of sound, useful matter put before us in a very practical and interesting form, but it requires careful study at home before definite opinions can be expressed upon it. I may, however, say, that in connection with my recent trip to Cape Town, and the investigations which I had to make in regard to the action of electric tramway currents upon submarine cables and other electric circuits, I found a maximum drop of voltage on one section in the return current along the rails to the power-house of five volts per mile. This large drop in voltage of the current returning to the power-house, had no doubt a great deal to do with the interferences on the submarine cable receiving signals, as well as local electrolytic action, and I proposed the introduction of negative or sucking boosters to reduce the potential of the rails to zero or a little below it at several places, as well as twin twisted cores for the submarine cable shore ends and other electric circuits which ran parallel and near to the tramway lines. These two modifications have overcome all difficulties. Upon my return to Glasgow I shall read Mr. Sayers' paper and the discussion thereon with interest, pleasure, and benefit. Professor Jamieson.

Mr. A. M. TAYLOR: Multiphase working, to which the author refers in the last section of his eminently practical paper, is an especially interesting subject from the point of view that we shall have, in the immediate future, to consider whether light railways as well as tramways can be worked economically by the multiphase system. (By the term "light railways" I refer more particularly to lines without ramifications, connecting populous centres to one another or to trunk Mr. Taylor.

Mr. Taylor. lines of railway, and which may have to traverse considerable distances where the population is very sparse.)

On the last page of the paper the distribution costs for the high-tension system are given as ·352d. per unit delivered at the car. As the advocates of multiphase transmission will probably try to reduce that, I have calculated incidentally how much it may be possible to do so. Some may claim that reduction could be made in the losses in the motor-generators; but even supposing that, for the sake of argument, we take an efficiency of 92½ per cent. (which would be an extremely high value, and could only hold where static transformers and rotary converters were employed, and hardly then) this item would only be changed from ·352d. to ·292d., which is of the order of the third of a penny on every unit turned out by the sub-stations. If, now, we take a long straight line and consider what we could do in that case with a comparatively infrequent service, the conditions are quite different.

Mr. Sayers has favoured the multiphase system, I consider, in the small allowance he has put in for attendance at the sub-stations, viz., 3s. per week per set, or 9s. per week per sub-station. It seems to me rather low, and I do not know how he is going to manage it; but perhaps he can tell us a little more about that. This item is distinctly in favour of the multiphase system. On the other hand, he has taken, as I have already said, a rather high value for the losses in the motor-generators. The result given in the paper for the cost of distribution is ·352d. per unit delivered to the cars. The limiting values are, under the most favourable conditions, for multiphase working about 0·292d., and under the least favourable conditions about 0·378d., for the size of system considered.

Now with regard to the question of a long, straight track; take a sub-station working three miles on either side of it, or six miles in all, and an infrequent service, say a half-hour service, as you might have on a light railway joining two towns with sparsely populated districts between, and you would have 20,000 motor-car miles per annum for every mile of line, or 120,000 motor-car miles per annum for the six miles. The resulting cost of distribution comes to 0·56d., or, if you take a 20-minute service, to 0·44d., for every unit delivered to the cars. Whether that is a practicable amount to have to pay as an extra item for the cost of distribution is, of course, questionable.

There are two statements in the early part of the paper which it is rather important to note; namely, that the distance to which we can distribute economically is not limited by the density of the traffic; also that the cheaper the cost of power, the *shorter* the range of economical distribution. On the first question it seemed a little strange that it should be so, and one thought of the gradients and how they would affect this distance. But, as I understand the paper, it seems that these do not affect the limit at all. The reason of the second statement is that Mr. Sayers' formula leads him direct to a particular current density for each case, which is higher as the cost of power is cheaper. Hence, having fixed his drop at 50 volts for every case, as a limit; that limit is reached at a less distance when the density is higher, i.e., when the cost of power is cheaper.

Lastly, as regards boosters, there is a little difficulty. I cannot quite understand Mr. Sayers' figures. He deals with the positive and negative feeders in some detail. It would appear that he proposes to let 3·16 miles go unboosted, and then to run the booster to supply the part which is beyond that, and he is only going to boost for the voltage that is beyond that (3·16-mile) limit. I think he will see, on reflection, that he must boost for *double* the number of volts that he proposes on page 706, as (the 50-volt limit of drop having been reached at 3·16 miles) the drop in the trolley wires, or distributors, working back from the point of connection of the feeder, must be taken account of as well as the drop in the feeder itself. Mr. Taylor.

Mr. Eustace Thomas: I have been very interested in Mr. Sayers' paper, the keynote of which is *economical* distribution. Probably the greater number of the systems which have been laid out have been based upon obtaining the cheapest system of cables rather than the most economical system, the limit in the reduction of the size of the cable having been considered from the point of view of current density and voltage regulation. Mr. Sayers has applied for this purpose Lord Kelvin's law, making the assumption that the cost of the cable would be proportional to the area of cross-section of the copper. Mr. Thomas.

Some time back I worked out a method of applying Lord Kelvin's law which took into account the variation in cost of insulation, while at the same time the calculations could be carried out in an exceedingly quick manner and were reduced directly to the cable-maker's price list.

The general principle of this method of calculation is as follows :—

Suppose that a cable having a resistance of R_1 ohms per mile is considered ; the cost of the energy which will be wasted per year will be proportional to the resistance R_1 and also to the length of the line, to the square of the current transmitted, to the number of hours of work, and to the cost of producing an extra unit of energy.

All of these except the resistance per mile will be unaffected by any variation in the size of the cable. We may therefore say that the cost of energy per year with this cable will be $R_1 \times K_1$, where K_1 is some constant.

If now we select the next size larger cable from the price list, having a resistance of R_2 ohms per mile, the cost of energy would in the same manner be $R_2 \times K_1$. There would thus be an annual saving amounting to—

$$(R_1 - R_2)\, K_1.$$

On the other hand the larger cable would cost more for interest, maintenance, and depreciation. If P_1 is the cost per mile of the first cable and P_2 of the second, then the interest, maintenance, and depreciation on the first cable will be proportional to P_1, and on the second to P_2. There will thus be an increase in the annual charges due to interest, maintenance, and depreciation amounting to—

$$(P_2 - P_1)\, K_2,$$

where K_2 is a constant involving the length of the cable and the rate of charges for interest, etc.

Mr. [illegible]

The two cables would be equally economical, and would be better than any other which could be chosen, if the saving due to the one were equal to the extra expense due to the other; that is if—

$$(R_1 - R_2)\,K_1 = (P_2 - P_1)\,K_2,$$

of these quantities R_1, R_2, P_1 and P_2 depend alone on the size of cable selected, while K_1 and K_2 depend entirely upon the conditions in the station. Hence we may say that the condition for greatest economy is

$$\frac{P_2 - P_1}{R_1 - R_2} = \frac{K_1}{K_2}$$

of which the left-hand side depends only upon the size of cable selected, while the right-hand side is independent of the size of cable and depends upon the cost of energy, rate of interest, length of the line, etc.

The exact value for $\frac{K_1}{K_2}$ is as follows:—

$\frac{K_1}{K_2}$ = *the current squared multiplied by number of hours working per annum multiplied by the cost of an extra unit of energy in £ divided by the rate of interest, maintenance, and depreciation and by* 1,000. (A rate of interest = ·1 would correspond to a 10 per cent. charge.)

In the following table the values of $\frac{p_2 - p_1}{R_1 - R_2}$ have been worked out. It should be noted, however, that these values are rather old and will of course depend upon the class of cable used.

Size	r	p	$\frac{p_2 - p_1}{R_1 - R_2}$
19/16	·7043	270	
			406
19/15	·5565	330	
			624
19/14	·4507	396	
			1130
19/13	·3409	520	
			1885
19/12	·2666	660	

A similar column can be added to price lists of all other types of cable employed.

An illustration of the calculations may be of interest. Suppose a cable is required to carry an average of 70 amperes 17 hours per day, while the cost of any extra Board of Trade unit is ¾d., and the rate of interest, maintenance, and depreciation may be considered as ·1 (10 per cent.).

$$\frac{70^2 \times 365 \times 17 \times \frac{1}{[illegible]}}{\cdot 1 \times 1000} = [illegible]$$

It will be seen that either a 19/15 or a 19/14 cable would be about equally economical, and either may be selected as other conditions may decide. I may say that in my own experience it has seldom been possible to employ this or any other rule for the best economy throughout the whole of the feeder, owing to some being long while others are short. Mr. Thomas.

In Mr. Sayers' lay-out for the one continuous-current station it will be found that the current density assumed for the shortest cable would cause the trolley wire at the point where this taps in to be commonly thirty volts higher in potential than at the points where the longer feeders are tapped in. This would have the effect of entirely disturbing the distribution which Mr. Sayers has assumed, and would render it necessary to work at different current-densities if the most equal distribution of potential on the trolley wire were desired. By somewhat modifying the feeders with a sectioned line, of course the distribution can be made anything that is desired.

I would like to emphasise very strongly a point which has been referred to by Mr. Sayers, but which does not seem to have been sufficiently appreciated in the discussion, namely, that the most economical *distribution* does not necessarily correspond to the most economical *system* considered as a whole. It might therefore be an advantage to employ the single generating station of Mr. Sayers' first scheme in place of the two generating stations of his second.

I am glad to see that Mr. Sayers approaches the question of one or two direct-current stations or a multiphase distribution with an entirely open mind. There is too much tendency at the present time to speak of an engineer as a "multiphase" or a "continuous-current" man. No engineer who is fit to decide upon the lay-out of a tramway station can afford to be designated in this way. He must be prepared to examine into the merits of every system and to employ in different cases entirely different arrangements. To tie oneself to one system argues, as a rule, a lack of experience.

Mr. BERNARD M. JENKIN: I should like to point out that this paper should not be taken in any way as comparing the relative merits of one station and two stations, or as comparing the continuous with the multiphase system. It is extremely interesting as a calculation of a particular case, but one cannot generalise in any way from it. I think that should be borne in mind very carefully. Again, I think Mr. Sayers says that feeders should be run to separate sections. This is a matter upon which it would be interesting if he would say a little more. It appears to me that it must depend almost entirely upon the number of cars running on the line and upon the nature of the line. Very likely the copper might be used very much more economically if you connected your feeder at a number of places with your trolley wire. Otherwise you might have sections lying idle without any car connected or any current upon them, and those feeders would be lying idle, whereas if the feeders are connected in parallel and also connected to the trolley wire the whole of the copper would always be employed. Mr. Jenkin.

Mr. E. K. SCOTT: I think the multiphase system would have looked very much better if Mr. Sayers had taken, instead of the primary voltage Mr. Scott.

Mr. Scott.

of 2,500, about double that pressure. Generating at 5,000 volts or higher would make a considerable difference to the first two items in the "distribution costs" table (page 720). If the distribution area is such that a pressure of only 2,500 will meet the case, then I think the continuous-current transformer system might very well be employed.

It is very interesting to notice in the table (page 720) that the cost of the motor generators is taken as £15 per kilowatt, and a little lower down the attendance, and oil brushes and sundries of these motor generators is calculated at £117 and £37 per annum respectively. Now compare this with multiphase traction—that is, with three-phase motors on the cars. First of all the transforming plant with its switch-gear is reduced from £15 per k.w. to less than £4 per k.w., and the 12½ per cent. for interest, depreciation, and repairs on £2,820 instead of £10,575 makes an enormous difference; then again with static transformers the two items for attendance and oil brushes and sundries are practically wiped out, whilst the efficiency of the transformation is very considerably increased. It will thus be seen that the distribution cost per unit delivered to the cars comes down from ·352d. to about ·2d. Of course, the higher the primary voltage and the greater the distribution area, the better does the case for multiphase traction appear.

Mr. Swinburne.

Mr. J. SWINBURNE: I have always some fear in hearing a paper like this that we are departing from accuracy with a view to getting simplicity of calculation. I am merely repeating what I said at our last meeting on another subject. Kelvin's law is Kelvin's law as long as it is simple, but as soon as you deal with the real circumstances there are all sorts of questions involved. The first and most obvious difficulty in applying anything like Kelvin's law is the question of insulation. Of course the cost of insulation does not vary as the cost of copper, and it goes up with the pressure, and that introduces one large departure. The next element of cost that I do not think tramway people ever consider nearly enough is the eating of pipes. Of course, generally, the pipes are not ours, and the cost need not be included. I suppose Tramway Companies fully understand the advantages of the English law on the question of eating pipes. The law, as far as I understand it, is this: if you are a private individual and eat anybody else's pipes you are liable for damages; but if you are a public company or under an Act of Parliament, then you can eat pipes as much as you like, provided you take ordinary precautions and do not eat more pipes than you can help. The Board of Trade is supposed to keep down the consumption of pipes, and generally, if you follow Board of Trade rules, as you have to, you are supposed to get off scot free. But seriously, I think this question of the corrosion of pipes is going to be one of the greatest difficulties we have to deal with in electric traction. I am going to depart from Mr. Sayers' paper a little and point out one method which I do not think has been sufficiently considered in this country, and that is the three-wire system. The ordinary three-wire system is applied in almost every case except electric traction. The Board of Trade rules at present do not fit this system at all. I do not think the three-wire system is contemplated. It has been discussed before this Institution once or twice, and there is no novelty in it. It is simply put

on one side without being considered at all. I believe the real reason is that some American has said they did not use the three-wire system in America, and since then nobody has ever thought of applying it. Mr. Swinburne.

The ordinary objection is that whilst in electric lighting you can generally balance your load fairly well, in traction the difficulty is very much greater, and is accentuated in tramway practice because you generally begin on a comparatively small scale, and you may have a lot of cars on one side of the road and none on the other. If you have a block, all the cars will collect on one side and you may have a very serious disturbance of balance. What I wish to point out is that the booster system is perfectly applicable to the three wires. The booster, if you think of it without preconceived ideas, is simply a series-machine excited in such a way that it will just excite itself on short circuit through its feeder at the distant point on the neutral conductor. The result is that a machine of that sort simply assists in preserving zero potential. A comparatively small booster on the three-wire system will do all that you want. The bigger your three-wire system, the easier it is to manage; whereas on the other system the bigger the system, the worse it is to manage. I cannot help thinking that, especially for very large districts and for large towns, the three-wire system with a booster on the middle return is very well worth consideration.

Mr. P. V. McMahon: On the three-wire system of the City and South London Railway we do not use boosters on the railway, but balancers. Mr. McMahon.

Mr. Swinburne: You are speaking of electric railways, I think, where you can control the two sides to some extent. I was talking of electric tramways where you have the electrolysis of pipes and an earth return, and where your system is a complicated net, not a mere line. Do you think the three-wire booster system can be applied to electric tramways? Mr. Swinburne.

Mr. McMahon: In an electric railway we sometimes get very much out of balance also. I have not seen the use of this system suggested before for tramways, but I do not see why it should not apply very well. Mr. McMahon.

Mr. R. C. Quin: I have only glanced at the paper since I came into the room, but I may say that I agree in general with all that Mr. Sayers has said, but there are one or two points on which I differ from him. The first one refers to the allowance for depreciation and maintenance of pipes and conduits being a good deal lower in the cable, and the statement that economy may be best studied by using the drawing-in system. With that I entirely disagree. I have used both systems, and my conclusion is that if you lay cables on the drawing-in system you will probably have to draw them out, and it is cheaper initially to lay cables down on a solid system than on the drawing-in system. I do not quite understand the tenor of Mr. Sayers' remark about the paving between the lines in municipal roadways. Does Mr. Sayers infer we should have no paving, or that it should be other than granite sets? Granite sets are not invariably used, but municipalities should insist upon *some special paving* between the tram lines, because the lines *are placed on the* crown of roads. The crown of the road always Mr. Quin.

Mr. Quin. wears away more quickly than the sides even on roads having no tramways, but when there is a tramway there it will wear out twice as quickly as it would if the tramway were not there. Every cart that goes along will take to the tramlines, and you have to provide for that traffic and for the horses pulling those vehicles, if you have not to provide for the horses pulling the tramcars. Personally, I very much prefer granite sets. If you provide the general traffic with wood pavement, as my Corporation are in the habit of doing, you get about 20 per cent. or 30 per cent. more traffic on the tramlines than you otherwise would. They do not like granite sets: I do.

There is another question to be considered other than the economical distribution of current in tramway systems, and that is the question of reliability. With all transformer systems we have an element of unreliability. We have something which is liable to break down, and I think that the value to be placed on reliability will be much more than a few pounds of copper.

General Webber. General C. E. WEBBER: It occurred to me with regard to the last speaker when he said that he was quite certain that the drawing-in system is a bad system, that his experience in the construction of underground electric lines must be very small. I have observed a good deal of tramway traction work lately, and it seems to me that both as regards the laying of cables and the erection of poles, some of the tramway engineers have much to learn from those who preceded them twenty or thirty years ago in telegraph work. The large quantity of telegraph cables which, in the sixties, were laid down, fixed in the ground, had to be taken up within a very few years, and drawing-in systems were universally adopted. The last speaker says he does not believe in the drawing-in systems, but I should have been very glad if he had given us his reasons. I think myself he might have given us one reason, namely, that a cable above a certain size, if it is insulated with lead enclosing paper insulation, is not conveniently or safely drawn in or out. Possibly then the best system is to lay the cable in wooden tarred troughs run in with bitumen.[1]

The other day, in a town not 200 miles from London, I was watching the erection of iron standards for the trolley wires. Although the strain on a trolley-wire pole and that on a telegraph pole are distinctly different in their characteristics, I think any one who has studied the strains in the two cases will at any rate erect their poles in such a way that they will not be likely to loosen themselves in the soil. In the example I mention I watched carefully a number of poles being erected, and, anything more crude, anything showing greater ignorance as to the conditions of placing a pole in the ground, I regret to say I have never seen before. If the young engineers who are growing up under the auspices of the Institution would study the question of the strain on poles placed in the ground, and the conditions and the manner of fixing the poles so as to resist those strains below the surface, they would find it a very interesting subject. If they were to

[1] *Since the meeting* Mr. Sayers has told me that he has adopted the "*drawing-in*" system with the largest lead-covered cables.

look at the paper (see *Journal of Society of Telegraph Engineers*, vol. ii., 1873, p. 40) by Lieutenant (now Colonel) Jekyll, R.E., which was published in the year 1873, on the question of strains on telegraph poles, although, as I have said, the conditions are very different, they would see there many suggestions which would be very useful and help them to consider how they should fix their trolley-wire poles. General Webber.

Mr. Reginald Wood [*communicated*]: Mr. Sayers is to be congratulated on his paper, and we are the richer by his observations. I propose to refer to only one point. Mr. Sayers states that in designing a feeder for use with a booster, it is necessary in making the calculation to debit the cost of the unit used in the feeder with the extra cost occasioned by the booster. Those interested in electric traction are apparently so accustomed to regard the booster as a convenient means for lessening the fall of pressure over the track, that they forget, or do not appear to notice, that the booster cheapens transmission. In any extended system the booster cheapens generation. It is therefore quite wrong to assume that the unit lost in a booster feeder costs more than the unit lost in an unboosted feeder. The mistake arises by comparing home feeding direct with distant feeding by booster. The true comparison should be between direct and boosted feeding for the same feeding points. In reading Mr. Sayers' paper one would conclude that by using unboosted feeders near home one was effecting an economy. The most economical method known is to use boosters in all feeders, providing the "boosters" are of proper design, and of course providing the disposition of the load is one suitable for boosters at all. The total capital and the total annual cost in a properly boosted system are both less than in an unboosted system. Mr. Wood.

The difference between lighting and traction is in the "form" of the load diagram and its size, and traction people appear to like irregular pressure. The designing of the feeders is the same for lighting and traction; the current density may be and usually is different. The design for trolley feeders is the same as for track feeders; the feeding points may be and often are, not coincident. As the track returns more current than the trolley wire takes, it is clear that the track feeders return less than the trolley feeders take. The track-feeding points are practically fixed by the Board of Trade, and the trolley-feeding points by division of the trolley wire. In general there are fewer feeding points and less copper on the track side. All this is on the assumption (not strictly true) that the form of the load curve on each feeder is the same.

One might ask why comparison of systems of transmission has so much fascination, why so many have tried it; and the answer appears to be that it takes a considerable amount of trouble to discover that a comparison on general lines is inconclusive. Each disposition of load must be tried on its merits, only rough generalisation is permissible. This is on transmission alone, without taking into account the effect of the system of transmission on the locality for generation.

By placing the boostered feeding points sufficiently close together, the fall of *potential in any* section of any distributing main, whether *trolley wire, track, or* any lighting main, may be made as small as *desired.*

Mr. Wood.

This is a function of the booster which is of great, in some cases of paramount importance. But the booster lays its claim to acceptance not on this secondary result, but on its primary achievement, which is to reconcile in the cheapest manner consumption at widely distant places and cheap generation in one place.

No doubt in the hands of a gentleman so experienced as Mr. Sayers accurate results are attained by including in the price of the unit lost in the feeders the interest, etc., on the part of the generating station used in producing it. The latter item is, however, the greater. Current density in the feeder depends on the form of the load curve, and perhaps it is near enough practically to say on the load factor. The relation between interest, etc., charges on the generating station, and the fuel, etc., expended also depends on the form of the load curve. It is clear, then, that any result based on combining interest and fuel charges can give the correct current density only for the corresponding load curve.

I do not know that I agree with Mr. Sayers that the unit lost in feeders should be priced at the same cost as that used in traction. There is much to be urged on the other side.

The term "negative booster" is rather common, but hardly accurate. A booster is not altered by being taken from the positive and inserted in the negative pole.

Mr. Trotter.

Mr. A. P. TROTTER [*communicated*]: In my "Note on Electric Tramways" communicated by Major Cardew, April 28, 1898, I discussed the design of return feeders chiefly with regard to the selection of the point of connection of the feeder with the rails. In the original form of this Note, written in November, 1897, I considered the question of minimum cost of the feeder and booster, neglecting the cost of energy to drive the booster. But on further consideration, I found that the cost of energy, so far from being negligible, was a most important factor. Knowing nobody at Cape Town with whom I could discuss the cost of energy or the rate of interest at which the amount should be capitalised, I wrote to Major Cardew to ask him to cancel the latter part of the Note.

But now that Mr. Sayers has attacked the subject from the other end, and has shown the importance of the cost of energy, my cancelled note may be published, and, with certain corrections made by Major Cardew, is as follows:—

"The sectional area of the return feeder varies inversely with the output of the booster which draws the current through it. Neglecting the cost of the energy, and the difference between the rate of depreciation of the feeder and of the booster, the capital expenditure will be a minimum when the cost of the feeder is equal to that of the booster. have ... a bare copper feeder erected on the tramway poles,[1] at 1s. per under t... cost of one mile, having a resistance of one ohm., is about £45. strain on ... of the booster may be put at £14 per kilowatt. Then the cost manner of ...er is surface, they

$$45l \times \frac{l}{r} \text{ or } 45\frac{l^2}{r},$$

[1] *Since the* ... "*drawing-in*" *sy*...de of erection, and the price, related to work at Cape Town.

where l is the length in miles, and r is the resistance in ohms. The cost of the booster is Mr. Trotter.

$$\frac{14\,c^2 r}{1{,}000},$$

where c is the current in amperes.

"Since

$$\frac{45 l^2}{r} = \frac{14\,c^2 r}{1{,}000}$$

$$r = \sqrt{\frac{3{,}200 l^2}{c}} = \frac{56{\cdot}6 l}{c}.$$

For 1 ampere for 1 mile, the resistance is 56·6. The watts expended are 56·6 and the booster costs £0·79, the feeder costs the same, making a total of £1·58 per ampere and per mile.

"Applying these results to the case represented by the line B H L M (see the figure in my Note, vol. xxvii., part 135, p. 458) we have 3½ miles and 130 amperes, and the cost of the feeder and booster would be 3·5 × 130 × 1·58 = £719. Would any economy be effected by tapping at the third mile with one feeder, and at the end of the rails with another, giving the distribution shown by the line B H N O P? The first feeder would carry 80 amperes, and have a length of three miles; the cost of the feeder and booster would be 240 × 1·58 = £379·2. The second would carry 40 amperes 5 miles, and the cost would be £316, making a total of £695·2 and a saving of £23·8, which would not pay for the trouble."

A day or two after sending this to Major Cardew, I learned that the cost of energy should be put, for the particular case in view, at 2d. per unit. The booster, according to the foregoing calculation, would have to do 25·67 kilowatts, and this would cost £2 10s. a day, or £912 10s. a year. Capitalising at 10 years, the sum of, say, £9,000 had to be added to the cost of the booster, which seemed so alarming that I wrote to Major Cardew to suppress all that part of the communication, and I never reconsidered the matter until Mr. Sayers took it up.

The form of the foregoing expression may be wrong, and other details may be added, but my object is to point out that economical distribution requires a very different design of conductors and boosters from that which would be obtained if first cost had been the only consideration.

Mr. H. M. Sayers, in reply: In answer to the questions which have been put to me more or less directly, I shall have very little to trouble you with. I feel that my paper has not met with much in the way of contradiction or destructive criticism. Mr. Taylor thinks my estimated cost of attention to motor-generators is low. I daresay it is. I have not had an opportunity of finding out what it actually is in practice, and I do not wish to take too high a figure. But this figure in the paper is not put forward as the actual working expenses of any particular system; these figures are simply assumed for arithmetical calculation in place of algebraic symbols. Therefore I am not prepared to go into Mr. H.M. Sayers.

Mr. H. M. Sayers.

details of how I could get the expenses down to 3s. per set per week. I think it may be done for not much more than that under proper arrangements and under favourable conditions. Mr. Taylor is quite right in saying that grades and density of traffic do not affect the limits of distribution. What they do affect are the sizes of the feeders to the section of line at which the grades or the dense traffic exist. With regard to his question as to trolley-wire boosters, I point out that for brevity I simply took one feeder to the centre of gravity of the district, beyond the limiting distance, and supposed that all the current was taken there. In practice one would run the booster feeders to a number of points, as he suggested.

Mr. Eustace Thomas gave us a valuable method of comparing two conductors for a given load. I would point out that the method which I have given here is more general, and that, as a matter of fact, if one takes a price list it will be found that over a really considerable range of sizes, cables of similar insulation cost a certain price per ton of copper insulated, and that price being taken with the other figures, as I say, one gets a general expression for the most economic density substantially correct for loads, within limits corresponding to the sizes of the conductors for which such price is correct.

Mr. Jenkin's remark that my paper must not be taken as a comparison of different systems is perfectly true; it does not profess to compare the different systems. He objects to the suggestion that feeders should be run to separate sections. I do not know whether he thinks I intend that each feeder shall only feed the trolley wire at one point. That is not assumed or intended at all, but I have found as a matter of practice that it is best in a large system at any rate to separate the trolley wires at various points, and to feed each section of trolley wire so separated with one feeder. It will be fed at several points, of course; on a busy system no loss occurs from that, and many advantages accrue. Mr. Scott wants to know why I do not assume 5,000 volts instead of 2,500 for the pressure of the multiphase system. He will find that it would make a very small difference to the costs as I have worked them, and as a matter of practice I should prefer to work with the 2,500. He is quite right as to the use of polyphase motors on the cars, and the very great difference that would make in the expense of the system. I have pointed that out in the penultimate sentence of my paper.

Mr. Swinburne's remarks as to the three-wire system are worthy of attention. I have always felt that this system is worth trying. There are many cases where it would seem to afford a way out of certain difficulties which we now experience. The difficulty is to find anybody who will put down the money for the experiment—because it would be an experiment, and there would be a great many details which would require working out. The difficulty in balancing between the two trolley wires is not imaginary. Of course the balancer is what one would naturally use to keep the voltage equal on the two sides. I believe there is an American experience of the three-wire system. I have seen illustrations of the overhead work, and the illustrations do not induce one to try it here, but in that case both wires, both positive and negative wires, are tapped by the trolley arms of each car, and that, of course

accentuates the difficulties. Mr. Quin seized on my sentence as to the drawing-in system and solid system. I should be very glad to give my reasons for preferring the drawing-in system, but it would take another paper to give them anything like full effect. But I may mention that experience of gas and water companies shows that a cast-iron pipe buried in an average soil has a life of 40 years, and that therefore a depreciation rate of 1 per cent. is sufficient to cover it. Mr. H. M. Sayers.

With regard to his further remark as to the construction of the track, I am not a permanent-way engineer, and I do not propose to discuss that matter any further, but I think a provision of greater conductivity in the track is worth study and worth experiment by municipal engineers. The municipalities will not allow us to make such experiments at all.

[*Communicated.*]—Mr. Wood's interesting communication calls for little answer, as it mostly agrees with my paper. I would point out to him that in charging the unit delivered through a booster with the energy used in the booster, I am acting quite correctly, as such charge is compared with the energy wasted, and the annual charges incurred in a cable. It is part of the cost of distribution, and cannot be neglected.

Undoubtedly the booster provides a cheaper means of keeping pressure up at a distant point than additional copper in the feeder in some cases. The track-feeder case shows this in an exaggerated form as compared with trolley or lighting feeders.

The load curve and the permissible variation of voltage over the distributing system are important factors in determining the most economical system, and I am glad to recognise how thoroughly this is understood by at least one reader of the paper.

The PRESIDENT: I will ask you to give a very hearty vote of thanks to Mr. Sayers for his paper.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members :

Edwin S. Jacob. | Frederick Thomas Trouton.

Associate Members :

P. Kerr Higgins. | Bradford Leslie.
Harold MacKnight Sillar.

Associates :

Richard Gilbert Allen.	Frederick James Lowe.
William John Blenheim.	David Herbert Patrick.
Spencer Flower.	John Francis Jodrell Reynolds.
Frederick Mason Hartley.	Henry Ellis Thompson.

Students :

Alfred Harvey Bennett.	George Eliot Turnbull.
Reginald Walter Penny.	Richard Westbrook.

The Three Hundred and Forty-Eighth Ordinary General Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, on Thursday evening, May 10th, 1900—Professor SILVANUS P. THOMPSON, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on May 3rd, 1900, were read and approved.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended in the Library.

The following transfer was announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

John McBean.

Messrs. Oswald Haes and B. G. Stewart were appointed scrutineers of the ballot for new members.

Donations were announced as having been received since the last meeting as follows :—To the *Library*, from Mr. Henry Wilde, F.R.S., Hon. Member ; to the *Building Fund*, from Major A. M. Stuart, R.E., Mr. J. F. J. Reynolds, and Mr. Mark Packer ; and to the *Benevolent Fund* from Mr. R. W. Weekes ; to all of whom the thanks of the meeting were unanimously accorded.

A FRICTIONLESS MOTOR METER.

By S. EVERSHED, Associate Member.

PRELIMINARY.

Lest there should be any misapprehension of the title of this paper, let it be said at once that the adjective is used in the comparative sense already sanctioned by such analogous phrases as "smokeless powder," "watertight compartment," and so on. Every one knows that smokeless powder makes some smoke, and that a watertight compartment usually leaks, but the smoke is not sufficient to enable the position of a gun to be seen nor to interfere with other military operations, and the leaks are not sufficient to sink the ship. Similarly a frictionless motor meter is one in which the friction commonly met with has been so greatly reduced as to render correction unnecessary, and reduce wear and tear to an inappreciable amount.

In the course of the last few years the author has tested some of the better known types of motor meter in general use, with the result that the lowest observed value for the moment of frictional resistance is 57 dyne cms. and the highest nearly 1,400 dyne cms., while values of from 300 to 500 dyne cms. are quite usual. All these tests were carried out upon new meters which had been carefully adjusted by the makers. In the author's meter the friction moments so far observed vary from 1·7 dyne cms. in a new meter up to 3·5 dyne cms. in one which has run for many million revolutions. These figures will, it is hoped, serve to excuse if not to justify the title "frictionless."

Among the many links in the long chain connecting the energy locked in the coal store of an electric-power station with the work done on the consumer's premises the supply meter is by no means the least important. Yet it has perhaps received less attention from the Institution of Electrical Engineers than any other essential part of an electric supply. It is difficult to assign any cause for this apparent neglect: electric meters began to be invented in the earliest days of electric lighting, and by the time the industry was on a sound basis there were already a large number, working on a variety of wholly different principles,

awaiting the test of practical use. There were motor meters, electrolytic meters, differential-clock meters, feeler meters—in addition to a host of nondescript meters. There were many kinds of each of the fundamental types; some of them based on more or less simple laws; others practically lawless and destined on that account to succumb in the struggle for existence. But the extraordinary activity of the meter inventor and the very wide field he was working in has left scarcely a trace in the Proceedings of the Institution.[1] While we have over and over again discussed every other link—coal, boilers, engines, dynamos, mains, batteries, transformers, lamps, and so on, and devoted a vast amount of learning and experience to efficiencies (reckoned to fractions of 1 per cent.), to load factors, to costs (calculated to minute fractions of a penny)—we have been content to pass the meter over in silence. Is the average meter, then, so good that it needs no attention from us? Far from it; erratic meters are not unknown. One will allow a consumer to run a lamp all day for nothing; another for 30 or 40 per cent. discount. Precious energy after having its cost ascertained to the hundredth of a penny is positively being given away every day by sticky motor meters, unbalanced clock meters, and the like. As a set off one hears of meters running up a big bill when the consumer is out of town and the main switch off.

Bearing all this in mind, the author feels that a paper devoted to the description of an attempt to remove some of the more obvious defects of a particular class of meter—the motor type—together with an exhibition of the outcome of that attempt will need no apology.

Motor Meters.

The fundamental principle of all motor meters is very simple. The driving moment (torque) of the motor is made proportional to the power (or to the current, in a coulomb or electricity meter) being metered, and the speed of the motor is controlled by a brake whose resisting moment is

[1] Here are the only papers on meters published from 1885 to 1899:—Mr. Hookham, in demonstrating his meter, 1889, vol. xviii., p. 688; Mr. Gibbings, "Registration of Small Currents used for Electric Lighting and other Purposes," 1898, vol. xxvii., p. 547.

proportional to the speed. Consequently the speed will be proportional to the power (or to the current), and the number of revolutions made in a given time will be proportional to the energy (or to the electricity) supplied. This was first clearly stated by Professors Ayrton and Perry in describing their well-known energy meter, the forerunner of nearly all energy meters since invented.[1] Unfortunately it is easier to lay down the law than it is to make a meter obey it. A motor axle must have bearings; a current has to be led to the rotating armature either by brushes or by means of a mercury bath; and there is a counting train to be driven. All these things involve friction, and a part, often a very considerable fraction, of the available driving torque will be used up to overcome it. There are other minor difficulties, such as the construction of a motor without iron, variations of electrical resistance due to temperature and so on, but practically friction is the only serious trouble in a motor meter; it limits the accuracy and involves a good deal of wear and tear.

If one attempts to design a practicable energy meter of the type described by Ayrton and Perry, one is hampered by certain fairly definite limitations, such as cost of manufacture, drop in the current coils at full load (or power wasted in them if that is the more important item), and above all waste of power in pressure circuit. If the full-load drop is fixed at one volt, and the wasted power in the pressure circuit is limited to three or four watts, it will be found that the maximum driving torque obtainable (on the assumption that the meter is to be saleable at present average prices) is something like 20,000 dyne cms., and the friction may be from 300 to 500 dyne cms. A greater driving moment is easily obtained by enlarging the armature, but only at the expense of increased weight of moving parts and a consequent increase in friction. We shall be fairly stating the result of careful designing if we put the driving torque at 15,000 and the moment of frictional resistance at 300 dyne cms.; in other words, driving torque at full load amounts to about fifty times the frictional resistance. It will be convenient to reduce these figures to percentages by calling the full load 100, maximum driving moment 100, and the friction moment 2, arbitrary units. We may also reckon full

[1] *Specification of Patent No. 2642–1882.*

speed of the meter as 100 revolutions per minute. Our hypothetical meter will obviously not start until the load exceeds 2. Also it will make 98 revolutions per minute at full load, since of the total driving torque of 100, two units are used up for friction, leaving 98 to work on the brake. Hence a table of corrections can be written down at once, on the assumption, of course, that friction is constant throughout the range of speeds contemplated. If there is no fluid friction this assumption is correct. The errors of the meter are given in Table I.

It will be observed that with such a meter the consumer gets a discount of 16 per cent. when he is taking one-tenth of full load.[1]

The range of a meter within specified limits of error forms the best criterion of comparison as regards accuracy, and the author proposes to call that part of the total range of a meter in which its error is within certain limits, the "Standard Range." Assuming the limit of error is fixed at 5 per cent.—or, which comes to the same thing, plus or minus $2\frac{1}{2}$ per cent—the standard range of the hypothetical meter is 1 to 3·3 when the meter is adjusted to register correctly at full load.

Correction for Friction.

Clearly the simple uncorrected motor meter requires some modification before it can be considered as a practical instrument. It is well known that friction can be partially corrected by means of a starting coil in the pressure circuit. At first sight this seems a simple and sufficient solution of the problem. If to the hypothetical meter we add a starting coil whose driving moment on the armature equals 2, the errors in Table I. disappear. A new error will, however, have crept in; the meter will almost invariably run when the load is zero; lessen the strength of the starting coil, and the meter, although not quite so immoral, will still occasionally go on running when the load is off. The author was for a long time completely baffled in his efforts to find an explanation of this effect, but a very

[1] Through the kindness of Professor Ayrton the author has been able to test an actual meter made in the manner described. Its maximum driving torque was 19,000 dyne cms. and its friction 350 dyne cms., the accuracy being therefore rather better than that shown in Table I. But this was dearly purchased at the expenditure of no less than 10 watts in the pressure circuit.

simple cause was at last discovered, and as others may have been puzzled besides himself he ventures to give the explanation here.

Every one knows how enormously the friction of light mechanism may be reduced by vibration. The reduction is far too large to be accounted for by the vibration causing cohesion to vanish. Now when a meter is fixed in a town house it is never entirely free from vibration, and the light axle such as is commonly employed in meters is alternating between a position in which it is wholly or partially out of contact with its bearings, and one in which it presses on them with more than normal force. In one sense, of course the average value of friction remains the same as it would be with no vibration, and, in fact, the constant of a meter is hardly altered appreciably by it; but the fact that friction is higher during one half period of the shaking and the meter therefore at rest (the starting coil is supposed just to balance the average friction—it is obviously insufficient to move the armature while the friction is above the average), does not prevent the starting coil from moving the armature during the half periods when friction is less than the average. The author has found that a meter fixed to the brick wall of the office building at Woodfield Works would go on running all night when the driving moment was reduced to a very small fraction of that required to balance the normal average friction; and this can only be accounted for on the assumption that during what may be called the positive half periods of vibration the meter axle and commutator were to all intents and purposes frictionless.

If this is the true explanation of a well-known trouble, then it is obvious that there will always be a difficulty with such meters when they are fixed in buildings subject to vibration.

Elimination of Friction.

Instead of regarding friction as unavoidable and attempting to correct for it, the author has approached the problem from another side and endeavoured to remove the causes of friction and so avoid the necessity for correction. These causes are, as has already been stated, (1) friction of axle bearings, (2) friction of brushes on commutator, and (3) friction of counting train and gear connecting it with

the motor axle. With an ordinary vertical axle the first is nearly all due to the bottom or step bearing, which is usually a rounded steel point resting in a jewel cup. In the author's meter the pressure of the axle on the bottom bearing is reduced to a few grammes by magnetically suspending the axle, armature, and brake. A top bearing is entirely dispensed with, the axle being held in position magnetically —"magnetically pivotted."

The brush friction is enormously reduced by the use of a novel form of commutator having elastic segments against which the edges of two light and freely pivotted wheels roll to act as brushes.

The friction of the train is entirely removed as a source of error. The train is driven by a simple electro-magnetic device whose speed of working is controlled by the speed of the motor, although there is absolutely no mechanical connection between them.

These means have already sufficed to reduce the friction from a value between 300 and 400 dyne cms. to less than 3 dyne cms., and there is reason for believing that the limit has not yet been reached.

Early Attempts at Magnetic Suspension.

The possibility of using magnetic force to take the weight of the rotary parts of a motor meter off its bearings has no doubt presented itself to many minds, and probably a good many inventors have made experiments with that object in view.

In 1887 Mr. Hookham refers to the subject in one of his meter patents, but he confines himself to the statement that "the magnets may be so disposed as to counteract or partially counteract gravity and thereby lessen friction."[1] A little later Mr. Ferranti turned his attention to magnetic suspension in connection with alternate-current meters, while quite recently in America Mr. Stanley has brought out a motor meter in which the vertical axle is entirely suspended by means of the attraction of iron discs fixed on the axle and ring poles surrounding them. Pivots at the top and at the bottom of the axle are required to keep it and the discs exactly concentric with the ring poles, the relative position of the discs and ring poles being one of

[1] Specification of Patent No. 4225**, 1887.

unstable equilibrium laterally, although perfectly stable axially.

The Author began experimenting with magnetic suspensions a few weeks after the publication of Professor George Forbes' paper on his "windmill" meter. It occurred to him that the Forbes meter might be made less wasteful of power if it were compounded much in the same way as a steam turbine, and he proposed to make

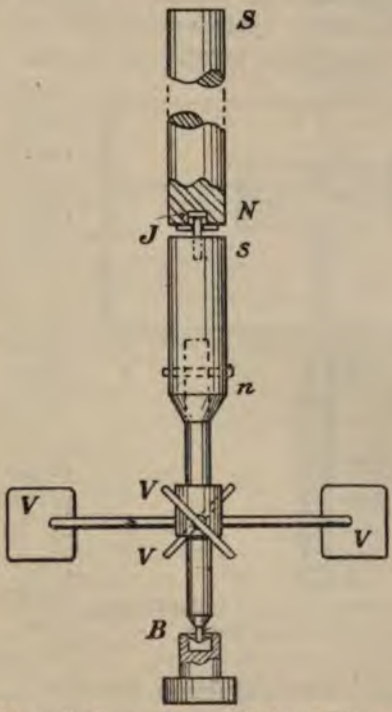


FIG. 1.—Magnetic Suspension applied to Professor Forbes' "Windmill" Meter.

the compound windmill as nearly frictionless as possible by magnetically suspending the axle and its series of rings of vanes. A meter was made on this plan with a bar magnet placed in line with and immediately above the end of the axle, which was pivotted top and bottom (see Fig. 1); the arrangement proved quite unworkable and was abandoned. In 1891 the Author, in connection with *Mr. Vignoles*, was working at a motor meter of the Ayrton-

Perry type, in which friction was eliminated by floatin the armature in water or oil. The armature was held in the centre of the vessel containing the liquid by means of a little iron rod projecting axially below the armature, with its end close to the bottom of the vessel (Fig. 2). A bar magnet was fixed underneath the vessel, in line with the iron rod, and with its upper pole as close as possible to the bottom of the vessel. The iron rod was consequently held in the magnetic axis of the bar magnet, and the axis of rotation of the rotary system coincided with the magnetic axis. This "magnetic pivot," as it was called, worked admirably, but the meter itself was a failure.[1] Another application of magnetic suspension was attempted in 1891–2 in connection with an early form of the Richards-Evershed Ships' Telegraph. In this apparatus a very powerful magnet is required to be freely pivotted and to have as little inertia as possible. An induced magnet was tried, magnetised by induction from an electro-magnet. The induction was led from the fixed to the movable magnet through the ends of the axle as shown in Fig. 3. The arrangement gave much trouble owing to the magnetic attraction forcing one or other of the pivots against the end of its bearing. In a modified form (see Fig. 4) the induction was led into the axle radially, and at the same time a little axial displacement was given to the enlarged part of the axle with respect to the fixed ring

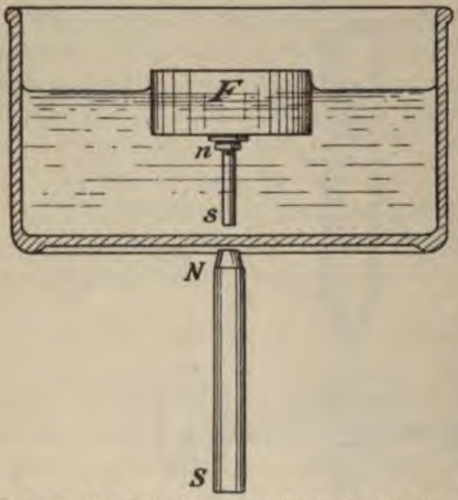


FIG. 2.—Magnetic Pivot applied to the Floating Armature of a Motor Meter.

[1] It is worth mentioning that the train of this meter was to be driven by a coil with a vertical axis fixed on top of the armature and alternately attracting and repelling a magnet; an idea which has, after the lapse of nearly ten years, been tested and proved to be entirely practicable.

pole in order to relieve the bottom bearing of the weight of the magnet N N and its heavy axle. This was accomplished to some extent, but two new difficulties arose; if the axle was not absolutely concentric with the hollow poles of the fixed magnet, there was a lateral magnetic-pull upon it causing the pivots to bear with corresponding pressure on their bearings, so that the elimination of one friction had only served to introduce another; the other difficulty arose from want of perfect mechanical truth in either the axle or the ring poles, or both. This led to the ring poles having a directing moment on the axle, and gave rise to errors in the indications of the Telegraph. In a sense these troubles were due to imperfect workmanship and were consequently avoidable. But anything requiring great nicety of adjustment was quite out of place in the particular apparatus of which the movable magnet formed a part, and after much fruitless work all idea of magnetic suspension was given up, and the whole magnetic circuit was made to move as one piece.

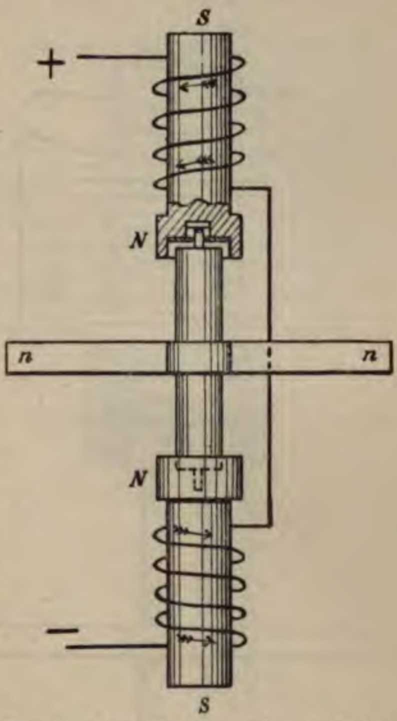


FIG. 3.—Magnetic Suspension, applied to the Needle Axle of a Ship's Telegraph.

In a renewed attempt to make a frictionless meter of the Ayrton-Perry type, the weight of the rotary part was suspended by the attraction of a fixed solenoid surrounding the upper end of the iron axle (Fig. 5). The magnetic circuit was made as perfect as possible by fixing an iron disc on the axle just below the coil and carrying an iron tube up from the disc so as to partially enclose the coil. It was, however, *not found* practicable to reduce the waste

of power in the solenoid below about five watts, and this was quite sufficient to put this form of suspension out of court so far as motor meters are concerned.

Present Form of Magnetic Suspension.

Finally the Author returned to the first idea (Fig. 1) of a simple magnetic pole fixed above an iron axle. Experience had proved that one of the worst troubles with all forms of suspension was caused by the magnetic axis not being absolutely coincident with the rotational axis, the latter being determined by the pivots. If the top pivot is removed, the axle is free to centre itself in a magnetically symmetrical fashion, and it will then rotate about the magnetic axis (Fig. 6). Any directional moment due to the axle and suspending pole not being perfect figures of revolution, will be enormously reduced by diminishing the diameters of axle and pole; and with diameters not much exceeding 5 mms. the supporting pole has no measurable directing influence upon the axle. Thus the combination of the suspension shown in Fig. 1 (minus its top pivot) with the magnetic pivot of Fig. 2 has resulted in a perfectly practicable and very simple arrangement for relieving a step bearing of the greater part of the weight of the rotating system.

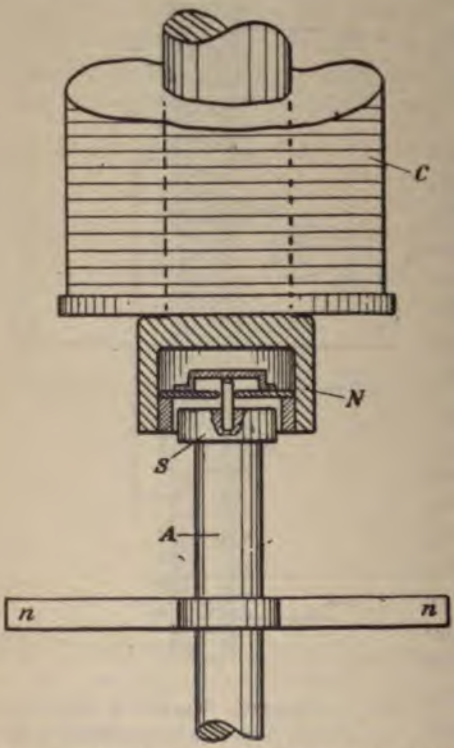


Fig. 4.—Modified form of Magnetic Suspension for a Ship's Telegraph.

To prevent the axle from accidentally coming into contact with the supporting pole, a thin plate of non-magnetic metal (seen at *c* in Fig. 6) is interposed between them. It is fixed immediately above the end of the axle, leaving a very small clearance. The supporting pole is adjusted until nearly the whole of the pressure on the step bearing is relieved. If the pressure is reduced to zero, a slight shake will jerk the axle up until it rests against the plate, where it will remain, since the upward attracting force increases as the space between axle and supporting pole diminishes. It is therefore necessary to leave a few grammes weight unbalanced so that there is sufficient gravitational force downwards to pull the axle off the end-plate, should it happen to rise into contact with it.

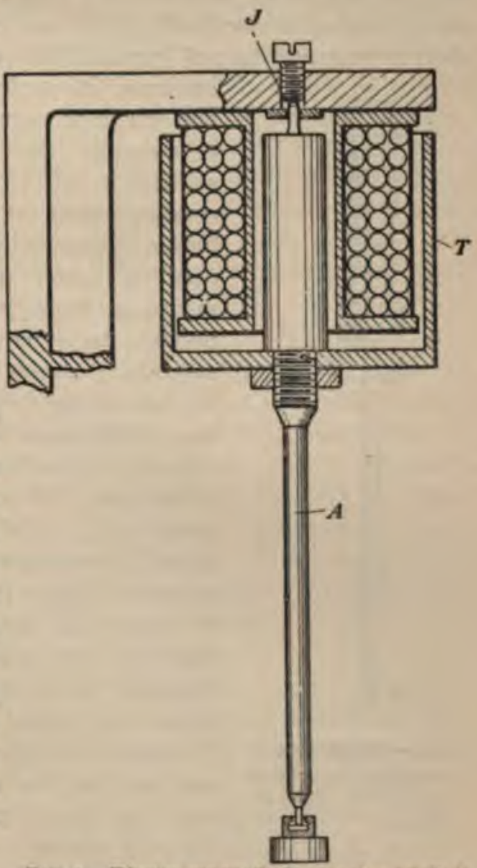


FIG. 5.—Electro-magnetic Suspension applied to a Motor Meter.

ESSENTIAL POINTS IN MAGNETIC SUSPENSION OF METER AXLES.

Magnetic attraction has been used to partially support the weight of dynamo armatures by the simple expedient of boring the pole pieces excentrically. Again, if a dynamo has a vertical axle, the whole of the pressure upon the step bearing may be removed by allowing the armature core to fall a

little below the level of the pole pieces; but these and similar applications of magnetism to the relief of bearing pressure must not be confounded with its use as a means of reducing the resistance to rotation of a meter axle.

Our object in magnetically suspending the axle of a moter meter is twofold. It is certainly an advantage to reduce wear and tear of bearing, but primarily we desire to improve the meter as regards accuracy and waste of energy, and to that end it is essential that there should be a reduction of all the resistances to rotation other than that offered by the brake. Now, while it is easy to suspend a meter axle by some such means as those just referred to as applicable to dynamos, a moment's consideration shows that in reducing the friction of the step bearing to zero, we have at the same time introduced a new source of friction, namely, hysteresis in the iron core on which the two pole pieces act. This, as is well known, offers a resistance to rotation. Its amount in any practical example will be found to be enormously greater than the frictional torque of the step bearing. In a dynamo or motor the hysteresis torque is there in any case, whether we suspend the armature or not, so that the relief of bearing friction by displacing the armature in the pole pieces is a clear gain, but in the meter there is no iron core within the armature, and in order to suspend the axle in the same way a core must be put upon the axle for that purpose, thus introducing a resisting torque which did not exist before.

FIG. 6.—Present form of Magnetic Suspension applied to a Motor Meter.

We thus arrive at an essential principle for magnetic suspension of meter axles: *The induction density in the magnetic devices used for support must remain absolutely constant during rotation of the axle.* This at once disposes of unsymmetrical bipolar arrangements; nothing of the nature of two poles attracting a piece of iron will serve. To secure

uniform induction density in the rotating part of the magnetic circuit, the attracting pole must be a figure of revolution with its axis coincident with the axis of rotation. As an example, the attracting pole might be a ring concentric with the axle; an iron disc fixed upon the axle a little below the plane of the ring pole would be attracted upwards, and if the ring and disc could be made mechanically true and magnetically homogeneous, the induction density would be uniform in the disc and there would be no resistance to rotation due to hysteresis. In practice it is exceedingly difficult to ensure these conditions. The disc is in unstable equilibrium transversely, and as there is necessarily a little clearance between the axle pivots and their bearings, the disc will always run a little out of centre; this at once raises the density at one part of the annular air-gap and lowers it on the opposite side, and during rotation the iron of the disc goes through a minute magnetic cycle, absorbing a corresponding amount of energy. The disc is also pulled sideways and causes the pivots to press against the bearings. These effects were very marked in the experimental devices already referred to (Figs. 3 and 4), and led the author to abandon that type of suspension for the simple form finally adopted, namely, a cylindrical magnetised rod fixed with its lower end immediately above and in line with the cylindrical iron axle.

It must not be supposed that this is a complete solution of the problem; but it has proved itself to be a thoroughly practicable one, and if the diameter of the supporting pole and axle is small enough, there appears to be no trace of hysteresis, nor is any difficulty experienced in obtaining the requisite mechanical truth. Of course the position of the axle is one of unstable equilibrium in a vertical direction, the magnetic attraction increasing rapidly if the axle rises towards the supporting pole. But if means are adopted to confine the possible travel of the axle within narrow limits, it will run with very little pressure on the step bearing.

Description of Frictionless Meter.

The essential working parts of the author's meter are shown in Fig. 7. The armature A, brake dish F, and train-driving coils D_1 D_2, are mounted on a mild steel axle a.

The axle has a hard steel point at its lower end resting in a jewel cup J; its upper end has no mechanical support, but

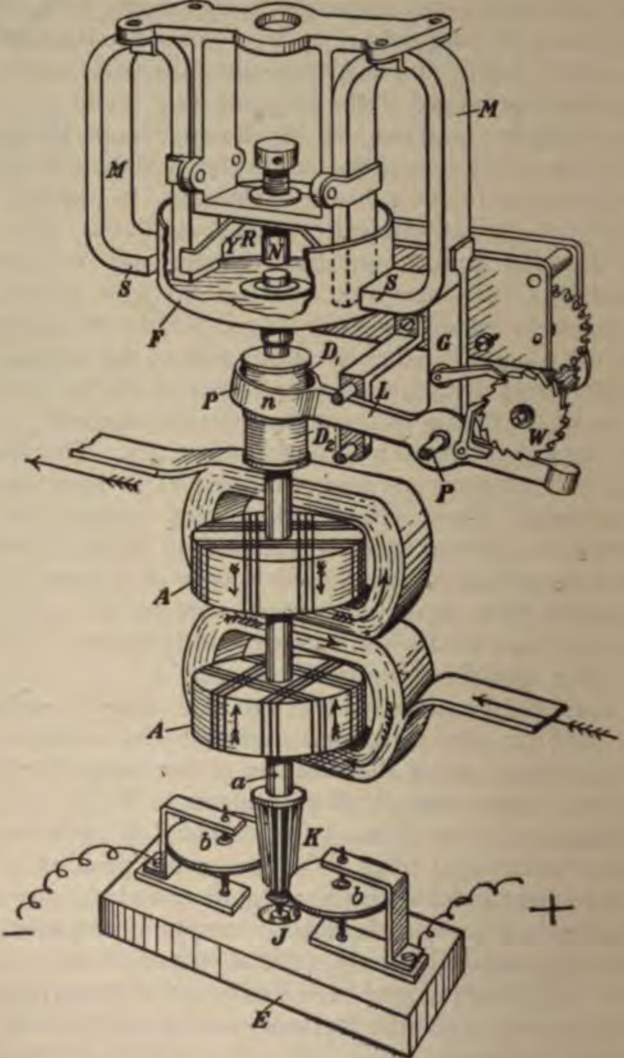


FIG. 7.—General Arrangement of Astatic Frictionless Meter.

is maintained in position by the magnetic attraction of an iron rod R, which is magnetised by the brake magnets M M through an iron yoke Y and forms the supporting pole.

The distance between R and the end of the axle is adjusted by screwing R in the yoke Y until the vertical force nearly suffices to lift the whole weight of the armature, brake, and other parts attached to the axle. The arrangement is more clearly seen in Fig. 8, which is a section through the magnetic pivot. A magnetic pivot of this type may easily be made to support a weight of from 100 to 200 grammes.

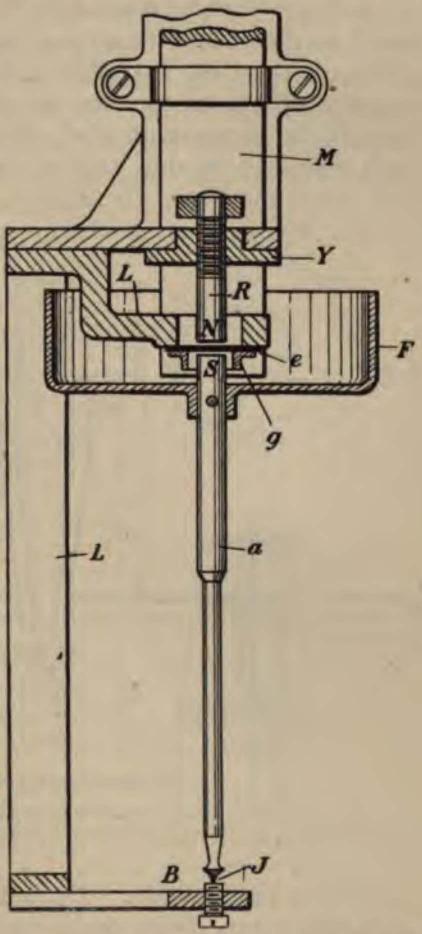


FIG. 8.—Axial Section showing Details of Magnetic Suspension in a Frictionless Meter.

M. Brake magnet; *Y* iron yoke between the brake magnets.
R. Iron rod forming supporting pole *N*.
a. Iron axle having upper end *S* beneath pole *N*.
e. End-plate (non-magnetic).
g. Guard ring to prevent axle from being displaced.
F. Brake dish.
B. Step bearing with jewel cup J.
L. Axle bearing frame.

The commutator K is placed beneath the armature, and the wheel brushes *b b* are pivotted in frames attached to an ebonite plate E. The commutator and brushes are shown on an enlarged scale in Fig. 9. The segments are fine iridio-platinum wires supported at one end in an ivory collet and entirely free at the other end, where they impinge and roll on the brush wheels. The commutator is about 3 mms. in diameter at the rolling circle; the wheels are about 36 mms. diameter, so that they make one revolution to twelve revolutions of the commutator.

The pressure current is led to the brush wheels through their frames, and to ensure good contact between frame and

wheel the step bearing of each wheel is an iridio-platinum pivot resting on a flat plate of the same metal.

A drum-winding is used for the armature, a break being made, in the ordinary course of winding, in each parallel, in order to insert the two little coils D_1 D_2. Thus D_1 is in series with one of the two parallels of the drum-winding, and D_2 in series with the other; they are consequently each traversed by one half of the whole armature current, and since they are, electrically, a part of the armature-circuit, the current in them is reversed twice in each

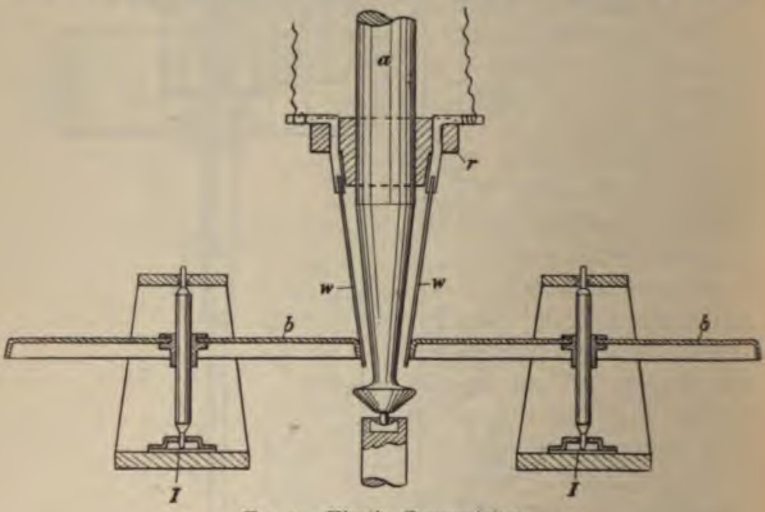


FIG. 9.—Elastic Commutator.

a, Axle *r*, Insulating collet; *w w*, Iridio-platinum wires forming commutator segments; *b*, Brush wheels; *p p*, Iridio-platinum pivots; *I I*, Iridio-platinum bearing plates.

revolution of the axle. D_1 and D_2 are inserted at corresponding points of the drum-winding, so that their currents reverse at the same instant, and they are coupled up so that the two currents flow in the same direction and to all intents and purposes D_1 and D_2 behave like one coil.

Fig. 10 shows the connections of the train-driving coils in diagrammatic form, a Gramme winding being substituted for the drum for the sake of clearness.

Surrounding the train coils D_1 and D_2, but not touching them, is a ring of soft iron P (Fig. 7), forming part of an iron lever L, mounted on an horizontal axle *p*. L is magnetised by induction from one of the brake magnets, an

iron bar G serving to complete the magnetic circuit between S and n. The induction leaves the ring pole P and passes radially through the train coils into the axle, and P consequently experiences a vertical force alternately upwards and downwards as the currents in the train coils periodically reverse. The result is that L oscillates on its axis, making a double stroke or complete cycle once in every revolution of the armature. The motion of the lever is limited by stops, and is communicated by means of a pawl to a ratchet wheel W, which is attached to the first axle of the counting-train T.

It will be seen at once that this device opposes no retarding moment on the armature axle. The only mechanical force called into play is in a vertical direction and has no component tending to turn the axle. The train coils and magnetised lever form a reciprocating electric motor, and, during the time the ring pole is moving up (or down) there is a back E.M.F. in the train coils, and the product of this back E.M.F. into the armature current and the time gives the consumption of electrical energy per stroke. It is, of course, equal to the mechanical work done—product of force on P into length of stroke. The force actually provided is far greater than that necessary to drive the train. The friction of an ordinary train is just overcome by a turning moment of about 4 dyne cms. applied to the worm or pinion commonly used on a meter axle to gear into the first wheel of the train; 6 dyne cms. will generally keep a train running at a speed a good deal higher than anything save a short circuit can produce. The Author has tested many trains taken out of different electric meters, and curiously enough they differ very little as regards friction.

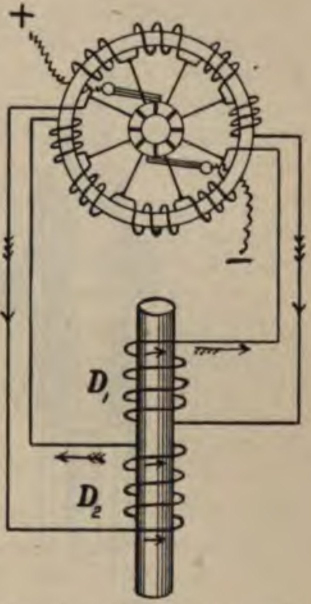


FIG. 10.—Diagram of Connections between Armature and Train Coils.

Now if the train were geared to the axle in the usual manner, and required a moment of 6 dyne cms. to keep it going, the work done by the meter in driving the train, being of course 2π times this moment in each revolution, would be about 38 ergs. The stroke of the train-driving lever is about 1·0 cm., so that the force upon it must be at least $\frac{38}{1·0} = 38$ dynes. The force actually obtained is about 750 dynes, which leaves an ample margin for accidental friction.

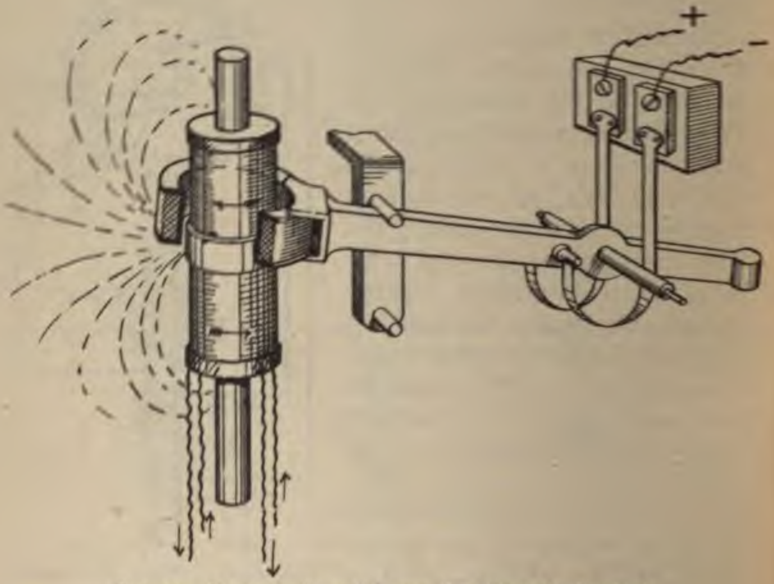


FIG. 11.—Train Coils and Lever for Alternate Currents.

It is assumed that the lever does no useful work on its return stroke.

A number of different forms of this train driver have been designed, and several of them have been tested in actual work. Fig. 11 shows a modification characterised by the same fundamental principle, namely, a coil producing an alternately upward and downward force upon the free end of a lever. In this modification the two train coils D_1 and D_2 are coupled back to back, so that they produce a consequent pole in the space between them, and the movable coil

attached to the end of the lever is alternately forced up and down. This coil forms part of the series resistance in the armature circuit, and carries the whole of the pressure current. Fig. 11 is intended for alternate-current meters, where a permanently magnetised lever would, of course, be useless.

There are other features in the design of the meter which will be of interest to station engineers, but which are hardly of sufficient general interest to warrant such a detailed description as has been given of the means adopted to reduce friction. The whole of the working parts of the meter, with the exception of the main current coils, are attached to a light framework, which is bolted to the top of the casting which forms the back, top, and bottom of the meter case. The other three sides of the case are formed by a bent sheet of zinc, which is screwed and sealed to the casting. The terminals project below the bottom and are covered by an insulating box, which may be sealed after connecting up on the consumers' premises. The Foucault brake is in the form of a shallow dish, and the two brake magnets are fixed in positions which make it impossible for any excess of current in the main coils to demagnetise them. Their stray field is at right angles to that of the main coils.

RANGE OF FRICTIONLESS METER.

A meter in which frictional resistance is so small as 3 dyne cms. will obviously have an unusually long range, even if nothing be done to correct the small remaining friction error. If the same limits are imposed as were assumed in making up Table I., namely, about 1 volt drop in the main coils and 3 watts wasted in the pressure circuit, the meter may be wound to give a maximum driving torque of 15,000 dyne cms. The friction is then only 0·02 per cent. of the full-load torque. The resulting range and uncorrected errors are set out in Table II.

It will be seen that the Standard Range of this uncorrected meter is 1 to 250. The range may be greatly extended by introducing a device to compensate for friction, and the very long range of such compensated meters may be useful in special cases.

The Author believes, however, that if advantage is taken

of the enormous reduction in friction to improve the meter in other ways, even at a sacrifice of some part of the long range, a more generally serviceable instrument will be secured. An examination of the available statistics[1] with regard to numbers of consumers and the lamps (or equivalent load) connected to the mains of the supply undertakings of this country, shows that on an average about fifty 8-c.p. lamps or their equivalent are wired per consumer. If we assume these to be 40-watt lamps, the maximum load of the average consumer will be about 2,000 watts and his minimum about 40 watts. Now, although the maximum demand of the consumer will not much exceed half this amount (the "maximum demand" for nine of the largest undertakings in London is 46 per cent. of the total load connected), the meter installed may be assumed to be wound for 2,000 watts, so that, if the meter is to register correctly at the smallest load, its range must at least be 1 to 50. It is, of course, quite probable that within a few years consumers will be using lamps taking far less power, but there is no reason to believe that the ratio of smallest load to maximum load will be much, if at all, affected by the introduction of more economical lamps. The Standard Range may then be reduced to 1 to 50, but any further decrease will be at the expense of revenue.

A reduction of range enables us largely to reduce the power wasted in the armature circuit, but a limit to this reduction is imposed by the fineness of the wire it is possible to employ upon the armature and in the series resistance. On this account it is at present not advisable to reduce the pressure current below 0·01 amperes, and this value has therefore been adopted for all voltages. The waste of power in the armature circuit is then 1 watt for 100 volts, 2 watts for 200 volts, and so on.

The voltage drop in the main coils may be left at 1 volt, this being only one-half per cent. on the 200-volt supply which is now being rapidly adopted. An additional improvement in accuracy has been secured by making the meter astatic, so that it is not affected by external magnetic forces.

[1] The author has made use of the excellent analyses published by *Lightning*.

ASTATIC METER.

The astatic meter has its armature divided into two equal portions, placed one above the other, on the axle, as shown in Fig. 7. These two parts, although physically separated, form one complete drum-winding connected to a single commutator. Following the process of winding a drum, the first coil will be wound on the lower spider; the second will be wound on the upper spider in exactly the same position as regards azimuth as it would ordinarily occupy if wound on the lower armature, but it is wound in the opposite sense. The third coil is on the lower spider; the fourth on the upper and reversed in sense. Thus numbering the coils in succession, all the odd numbers will be found on the lower half armature and all the even numbers will be found on the upper half.

Each half armature is surrounded by its own pair of main-current coils, the two pairs being coupled so that the current flows in them in opposite senses, their magnetic fields being in opposite directions. This reversed coupling is, of course, necessary to drive both parts of the armature the same way, but it has the incidental advantage that it greatly reduces the stray field of the main coils, and so renders the brake magnets doubly secure against excessive currents.

The advantage of an astatic armature is, however, only gained at the cost of a reduction in driving torque, for a little consideration will show that when a non-astatic drum armature is converted to the astatic form shown in Fig. 7, and one half of the copper on the main coils is taken off and made up into a second pair of coils, so that each of the two parts of the armatures may be driven, the field in which the armature rotates is halved although the number of turns on the armature itself remains the same as before. Probably very few consumers possess the requisite combination of knowledge and knavery to enable them to attempt a reduction of their electric light bill by the use of a strong magnet placed near the meter, but meters are always liable to be fixed in positions where stray fields exist, and the author is inclined to believe that the astatic armature will prove to be a clear gain.

To *sum up—the* astatic meter is wound to give a driving

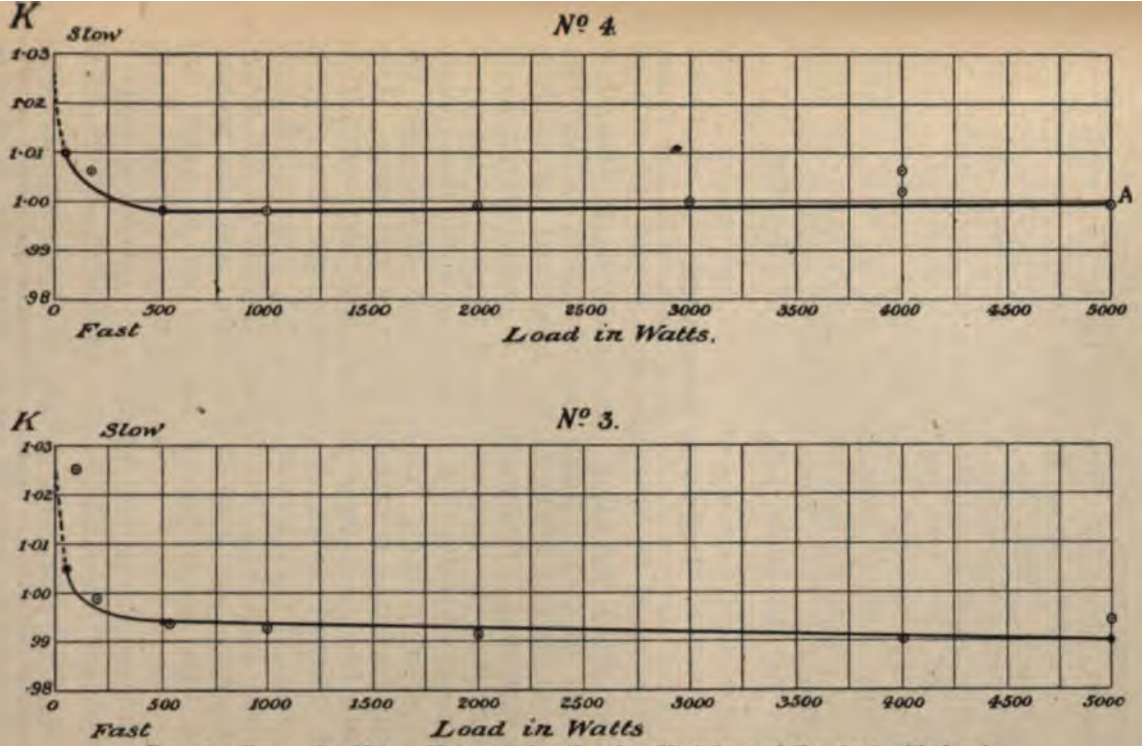


FIG. 12.—Curves for Meters Nos. 3 and 4 showing Variations of Constant with Load.

• Points determined by the Author in July, 1899.

⊙ Points determined by Mr. Rennie at the Board of Trade Laboratory, September, 1899. At *A*, Mr. Rennie's observation falls exactly on a point determined by the Author.

N.B.—The horizontal lines are drawn at intervals of one per cent.

torque of about 2,000 dyne cms. at full load; the current in the armature circuit being 10 milliamperes and the drop in the main coils 1 volt. The frictional resistance is about 2 dyne cms. when the meter is new, and the tests to be presently referred to show that a frictionless meter will run for many million revolutions before any serious increase in friction takes place.

Compensation for Remaining Friction.

The initial value of friction is compensated for by means of a little strip of sheet iron placed within the field of the main coils. When once magnetised by the main current the coercive force of the iron is sufficient to provide the very small driving moment required to overcome friction. As has already been pointed out, compensation for friction will cause a meter to run at no load if it is subjected to vibration; but when friction is only a very minute fraction of the maximum driving torque, the over-registration of a corrected meter would be quite negligible even if it could occur, but as a matter of fact the elastic commutator has a directing moment upon the axle which prevents the meter from running until the driving torque is two or three times as great as the moment of friction. Hence it is impossible for the compensator to start the meter or to keep it running. The corrected meter starts with from 1/500th to 1/300th of full load, and has a standard range of about 1 to 200.

The range and accuracy of a corrected meter are well exemplified by the two curves given in Fig. 12, which show the variation in the constants of two meters having a ratio of about 1 to 1,250 between friction and full-load torque. This happens to be approximately the same ratio as that it is proposed to adopt as a reasonable compromise between the conflicting elements of accuracy and waste of power, so that although these meters have a much larger frictional resistance than is now obtained, yet as regards accuracy and range they are very nearly identical with the astatic meter. The latter has much less driving torque, but its frictional resistance is smaller by a corresponding amount.

The larger friction in Meters Nos. 3 and 4 arises from the fact that they were made before the adoption of the

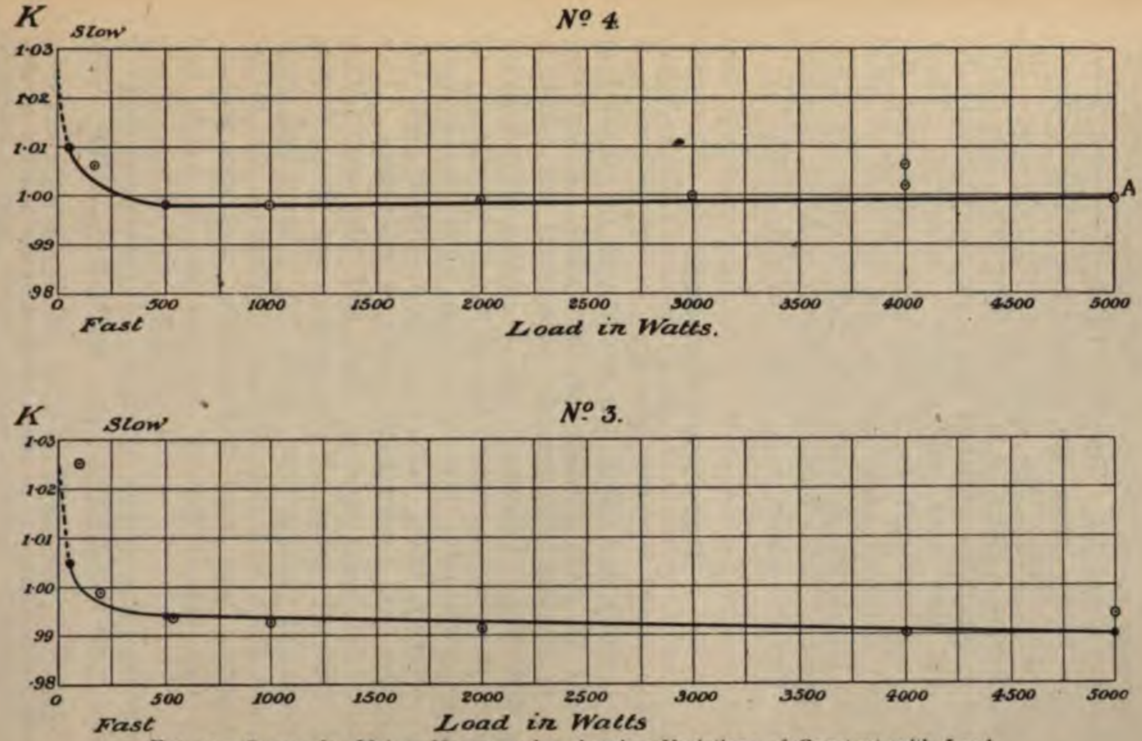


FIG. 12.—Curves for Meters Nos. 3 and 4 showing Variations of Constant with Load.

• Points determined by the Author in July, 1899.

⊙ Points determined by Mr. Rennie at the Board of Trade Laboratory, September, 1899. At *A*, Mr. Rennie's observation falls exactly on a point determined by the Author.

N.B.—The horizontal lines are drawn at intervals of one per cent.

elastic commutator and other improvements. They are fitted with very small commutators with rigid sections made of iridio-platinum wires, which form a sort of squirrel-cage round the axle. The diameter of the commutator is about $\frac{1}{16}''$. Fine wire brushes are used, pressing very lightly upon the commutator. The frictional resistance in Meter No. 3 is 79 dyne cms., and the driving torque at full load is 10,000 dyne cms. The corresponding quantities in Meter No. 4 are approximately the same, but they were not accurately measured. These meters are corrected by a thin steel rod having the necessary coercive force, and, as will be seen on reference to the curves, they are both slightly under-corrected. The Board of Trade limits are, however, nowhere exceeded throughout the whole range from 0 to 5,000 watts.[1]

Tests for Endurance.

There would be little advantage in any reduction of friction which was either not permanent or obtained at the cost of great delicacy of adjustment, and therefore liable to increase whenever the adjustment was accidentally disturbed. Prolonged trial in actual service is, of course, the only conclusive test of the trustworthiness of any novel apparatus, but the tests to which the frictionless meter is being subjected show already that the mechanism has a remarkable power of endurance. Two meters had been made in 1898, and after many trials with different forms of commutator and train driving apparatus, in the course of which No. 1 meter had made between three and four million revolutions, the elastic commutator was fitted to this meter, and after preliminary tests for friction it was put on to a 100 - volt circuit on the 25th of May, 1899, and driven at 80 revolutions per minute by means of permanent magnets placed near the armature, this method of driving being

[1] Meters Nos. 3 and 4 are in use in the meter testing department of the Manchester Corporation as standards for checking the accuracy of other meters intended for commercial purposes, and the author is indebted to Mr. Wordingham for his permission to make use of the curves which accompanied the Board of Trade certificate. He desires also to thank Mr. Rennie, who very kindly supplied a copy of the tests made at the Board of Trade Laboratory.

adopted in order to avoid waste of current in the main coils. This meter has been running continuously since that date, with the exception of the few hours occupied in making friction tests. The tests made up to the date of writing are given in Table III. The revolutions are reckoned from the day when the test began, and give the total made by the commutator correctly; but, as already mentioned, the meter had previously run for over three million revolutions, so that the step bearing has been subjected to so much more wear and tear. The standard pressure current is 10 milliamperes, but for the purpose of this test it was raised to 18·2 milliamperes in order to make the energy running down in sparks upon the commutator when the train coils are reversed the same as it is with the standard size of train coil—No. 1 being fitted with a smaller train coil. This increase of current increases the sparking on all the sections, so that the total energy tending to destroy the commutator is far greater than it is with a standard train coil. During the first few weeks some sparking was visible, but this has gradually diminished until at the present time sparks are only seen occasionally. There is no apparent wear either on the commutator wires or on the brush wheels. Platinum in the form of black powder clings to the inside of the wires, and has also settled in a ring round the axle inside the commutator; otherwise there is no visible change. It is possible that the presence of the powder accounts for the diminution of sparking; the energy may be absorbed in heating up the powder, which quite possibly acts as a variable resistance, and so ensures a gradual reduction of the current to zero instead of a sudden interruption and consequent spark. On the other hand the commutator may still be sparking as at first, and the powder may simply prevent the sparks from being seen.

As soon as it was seen that the elastic commutator was a step in the right direction, No. 2 meter was similarly fitted, but with a commutator having much finer wires—about 4 mils. diameter—and with brass brush wheels lightly gilt upon their edges. After long tests with different pivots, during which time the elastic commutator made three and a half million revolutions, No. 2 meter was put on *to the 100-volt* circuit on October 12th, 1899, and it has

been running at about 57 revolutions per minute day and night since that date. Periodical friction tests have been made, and the results are given in Table IV. No. 2 meter is fitted with a standard train coil and the pressure current was therefore fixed at the normal value—namely, 10 milliamperes. No appreciable wear is visible on the commutator wires, but a curious change has gradually become apparent in the brush wheels. Where they roll in contact with the iridio-platinum wires their edges have acquired a smooth deposit of platinum, and under a magnifying glass they have the characteristic appearance of a surface which has been platinised by the ordinary electro-chemical process.

During these tests no adjustments or alterations of any kind have been made in the meters, nor have any precautions been taken to keep dust and dirt away from them. They are running in a dirty workshop with loose covers over them, and the slowly increasing friction noticed with No. 2 meter is probably due to the collection of dust—which is very visible—within the step bearing and in the brush-wheel bearings. The normal speed at full load has been fixed at 50 revolutions per minute, so that No. 2 meter is running 14 per cent. and No. 1 meter 60 per cent. above full speed.

If we assume the average consumer to use the equivalent of 1·8 hours at full load each day, his meter will at the above speed (50 revs. per minute) make 2,000,000 revolutions per annum. No. 2 meter has therefore been subjected to wear and tear corresponding to five years' service, while No. 1 meter has run for a period corresponding to about 14 years. These figures are mentioned in order to enable the value of the tests to be estimated with some sense of proportion; they are not adduced as in any way a substitute for the test of hard work under all the varying conditions necessarily imposed upon supply meters in every-day use.

Possibility of Further Reductions in Friction.

The results so far obtained and an examination of the causes of the remaining friction afford some ground for believing that its limiting value has not yet been reached. The calculated value of the total frictional resistance in Meter No. 2 (see Appendix) is 1·6 dyne. cms., 1·1 being

attributable to the step bearing and 0·5 to the brush-wheel bearings. It is quite possible to use aluminium wheels and so reduce the pressure on their step bearings to about one-half of the present amount, reducing this part of the friction to 0·25. The pressure of the steel point upon the jewel of the armature axle bearing can be reduced by coupling the train coils back to back, as in Fig. 11, so as to eliminate the effect they now have in alternately increasing and diminishing the induction through the axle and supporting pole. If at the same time some means can be found to prevent the axle from accidentally rising from the step bearing, the only absolutely unavoidable pressure downwards will be about 1 gramme, an amount which is, of course, necessary to prevent the mutual force between the train lever and the train coils from lifting the axle. To err on the safe side, we may assume that it is possible to reduce the pressure from 12 grms. to about 2 grms., the corresponding reduction in friction being from 1·1 to about 0·2 dyne cms. Hence it seems not impossible to reduce the 1·6 dyne cms. of total calculated friction to 0·45, or say 0·5 dyne cms., a reduction of 1·1. This should be subtracted from the lowest observed value of the frictional resistance in No. 2 meter, and would bring the initial friction in a new meter down to about 1 dyne cm.

Again, the moment of frictional resistance per gramme weight upon the step bearing depends on the acuteness of the steel point resting upon the cup jewel. In the meters hitherto tested no attempt has been made to secure a fine steel point. The point having been ground to an angle of about 30 degrees, is rounded off at the tip until it forms a hemispherical end of from 5 to 7 mils. radius. This rests in a sapphire cup of from 20 to 40 mils. radius, and although two spherical surfaces of different radius ought to touch in a point quite independently of the ratio of their radii, it is obvious that in practice we must look upon our spherical steel point as one with a rough surface making contact with the jewel in a number of points distributed over a very small and approximately circular area, the diameter of which will depend on the ratio of the radii of jewel and point, and *upon the smoothness* of the two surfaces. Now as the

formula for point friction indicates (see Appendix), the moment of friction is proportional to the diameter of contact, so that we may expect a decrease in moment if we diminish the radius of the spherical point—an expectation which is, of course, borne out by the result of everyday experience. Whether the reduction so brought about will be permanent depends on how far the gradual burnishing of the steel by the jewel is affected by the pressure per unit of contact surface, and on the effect of the burnishing itself upon the co-efficient of friction. No data drawn from engineering experience are likely to afford any clue to the answer to these questions, and no means have hitherto existed for obtaining a direct answer by experiment. The Author is now investigating the behaviour of different kinds of step bearings for use in meters with a view to the determination of the type having the greatest power of endurance.

Engineers accustomed to dealing with power in kilowatts and friction measured by hot bearings will be inclined to regard all such discussion of apparently insignificant details as so much industry wasted in the splitting of hairs. It will however, be agreed that we cannot be said to have solved the problem of metering electric energy until meters possessing an adequate range and accuracy can be so constructed that they may be relied upon for many years' service without need of adjustment or repair.

In this matter we may learn something from the gas meter, of which—in spite of much unmerited and ignorant abuse—it may safely be said that while in point of accuracy it compares not unfavourably with the average electric meter, in other respects it is far in advance of any electric meter at present in use. The value of gas to a consumer depends upon its calorific and illuminating powers, and only in a minor degree upon its pressure. Hence the gas meter may, and does, absorb a large fraction of the available pressure without much disadvantage to the user, and its remarkable power of endurance has been brought about by the use of a motor capable of doing a far larger amount of work than is required to overcome friction, even when the mechanism is much worn by use. A properly made gas meter may be in-

stalled upon the consumer's premises and remain there in constant use without adjustment or repair of any kind for from ten to fifteen years before the motor is sufficiently worn to cause a serious error. With an electric supply, on the other hand, energy is what the consumer wants and what he pays for, and for lighting purposes he must have the energy supplied at constant pressure; hence the electric meter cannot be allowed to absorb more than a very small fraction of the energy and pressure of supply. The mechanical power of the electric meter being therefore limited by the conditions of supply, it is only by diminishing friction and wear and tear that we can hope to attain and maintain the required accuracy throughout many years of service. From this point of view it is clearly of the greatest importance that every cause of mechanical friction should be ascertained and as far as possible removed. It was with this conviction that the Author, quite in the early days of public electric supply, set about devising means for diminishing meter friction, and the outcome of a good many years of experimental work is the meter described in this paper. It is not claimed for it that it is in all respects the ideal of what a meter should be, but the Author hopes it may be regarded as a step in the right direction.

NOTE.—The Author desires to acknowledge his indebtedness to Mr. Cox, who has the charge of the Experimental Department at Woodfield Works. During three years' continuous work upon the meter Mr. Cox's fertility of resource and inexhaustible patience have surmounted many difficulties and led to numerous improvements.

APPENDIX.

CALCULATION OF ARMATURE TORQUE, BRAKE TORQUE, AND FRICTIONAL RESISTANCE.

I. ARMATURE TORQUE.

In designing an Ayrton-Perry motor meter the driving torque may be calculated from the formula—

$$d = \frac{H\,a\,N\,C}{\pi},$$

which gives *the torque d in* terms of H the field of the main current

coils, a the area of the average turn of wire on the armature, N the total number of turns in the armature winding, and C the whole pressure current from brush to brush.

A sufficiently close approximation to the true mean value of the field throughout the space occupied by the armature is obtained by calculating H at several points of the axis of the main coils, and taking an average. When the coils are rectangular, the field on the axial line may be deduced from the formula—

$$H = \frac{8 C \sqrt{p^2 + q^2}}{p q},$$

which gives the field at the centre of a wire rectangle whose sides are p and q. If the coil is square, this reduces to

$$H = \frac{8 \sqrt{2} C}{p},$$

p being now the side of the square. The field at the centre of a circular wire being

$$H = \frac{2 \pi C}{r},$$

we find that if $r = \cdot 56 p$ the circular and square wires will have the same field; hence for purposes of calculation a circular coil of appropriate radius may be substituted for the square coil.

There are, of course, various methods for arriving at an exact value for H, but as they involve applications of spherical harmonics they are far too cumbersome for practical use in design.

When the meter is made, its driving torque is easily measured by passing a fine thread round the axle and hanging a known weight on the end. When the axle is vertical, the thread is brought out in a horizontal direction from the axle and passed over a freely pivotted pulley, from which it hangs down carrying the weight at its end. To avoid side pressure against the axle bearings it is desirable to use two threads brought away from the axle in opposite directions and each carrying half the weight so that a proper turning moment is produced. Having adjusted the thread and weights, current is turned on, and varied until the armature torque just balances the weight. When the full-load torque is small, it is desirable to make this measurement with two or three times the full-load current, otherwise the weight required will be too small to enable accurate results to be obtained. The calculated torque is found to agree within 2 or 3 per cent. with that obtained directly by measurement.

II. Brake Torque.

The difficulty of determining the average path of the eddy current in a given brake conductor prevents us from predetermining the torque unless we have previously ascertained the effective electrical resistance of the current path in a brake of similar shape. There are, however,

some general principles applying to the design of Foucault brakes which may be shortly stated here.

Consider a cylindrical conductor, of radius r, spinning on its axis between the poles of a magnet. Let the polar gap have a breadth b and axial length l, and let the field within the gap be H. Then if x is the electrical resistance of the current path, and ω the angular velocity of the cylinder, the current generated will be—

$$C = \frac{H\, l\, r\, \omega}{x}.$$

Now the force between conductor and magnet is H l C, hence the torque will be

$$M = \frac{H^2\, l^2\, r^2\, \omega}{x} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

When the cylinder extends axially for some distance beyond the poles in both directions, x becomes simply proportional to the resistance of the metal in the gap. Now this resistance is

$$\frac{\rho\, l}{b\, t},$$

t being the thickness of the metal. We can therefore write—

$$x = k\frac{\rho\, l}{b\, t}.$$

The value of k depends on the shape of the polar area, and on the extent of conductor outside that area. The author finds k varies from about 3 for a square or circular area of gap up to 6 or 7 with oblong poles, even as high as 9 or 10 when there is very little metal beyond the poles. Inserting the value just given for x in equation (1) and multiplying both numerator and denominator by b, we get—

$$M = \frac{H^2\, l^2\, b^2\, r^2\, \omega\, t}{k\, \rho\, b\, l},$$

or

$$M = \frac{B^2\, r^2\, \omega\, t}{k\, r\, b\, l} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

from which we see that for a given value of total induction B passing through the brake cyclinder, the torque increases as the area $b\,l$ is diminished. This deduction is well borne out in practice, and by giving the brake magnets conical poles ending in a circular gap of small diameter the torque for a given weight of magnet is considerably increased; or, what is generally more important, for a given torque the weight of metal in the brake may be greatly reduced by using magnets with conical poles.

The formula also shows the advantage to be gained by increasing the diameter of a cylindrical brake; since the weight only increases in simple proportion, while the torque increases in proportion to the *square of the radius.*

III. FRICTIONAL RESISTANCE.

When mechanical friction is a fairly large percentage of the full-load torque, air friction may be safely neglected; the only retarding forces are then mechanical friction, which is practically constant, and the brake which is proportional to the speed. Hence if s_1 and s_2 are the observed speeds with two torques d_1 and d_2, we have—

$$d_1 = f + b\,s_1, \quad d_2 = f + b\,s_2,$$

where f is the torque required to overcome friction, and b is the brake torque at unit speed. Hence

$$b = \frac{d_1 - d_2}{s_1 - s_2}, \text{ and } f = \frac{d_2 s_1 - d_1 s_2}{s_1 - s_2}.$$

To get accurate results, stray fields must be eliminated by reversing the current in the main coils and taking a second set of readings with the same numerical values for d_1 and d_2.

In testing the friction of a "frictionless" meter, the greatest care is required in measuring speeds and torques, and it is necessary to reduce the strength of the brake to a small fraction of its normal value in order to obtain anything like accurate results, for obviously errors of observation have a rapidly increasing effect on the determination of f as the two quantities $d_2 s_1$ and $d_1 s_2$ approach each other in magnitude. Each of the results given in Tables III. and IV. is the mean of a number of observations, and to avoid effects due to want of truth in the brush wheels the speeds were deduced from the times taken to make 12 (and multiples of 12) revolutions of the armature, corresponding with whole revolutions of the brush wheels. Even with the utmost care, discrepancies of as much as 10 or 15 per cent. in successive tests are quite usual when the friction is under 3 dyne cms.

When the armature and brake of a "frictionless" meter are both figures of revolution with smooth surfaces air friction is inappreciable up to speeds of 40 or 50 revolutions per minute, but when there are any parts attached to the axle which can have a fan action, air friction becomes evident, and although it would cause no appreciable error in the registration of the meter when the normal brake is in use, it will, if not taken into account, lead to an underestimate of the mechanical friction. To avoid this, observations are made at three speeds in order to determine a the coefficient of air friction, as well as f and b.

Thus assuming the air friction of a rotating body to be proportional to the square of the speed, we have—

$$d_1 = f + bs_1 + as_1^2\,;\ d_2 = f + bs_2 + as_2^2\ d_3 = f + bs_3 + as_3^2,$$

from which we first find a, then b, and finally the mean value of f.

$$a = \frac{(d_3 - d_2)(s_2 - s_1) - (d_2 - d_1)\,s_3 - s_2)}{(s_3 - s_2)\,(s_3 - s_1)\,(s_2 - s_1)}$$

$$2b = \frac{d_3 - d_2}{s_3 - s_2} + \frac{d_2 - d_1}{s_2 - s_1} - a\,(s_3 + 2s_2 + s_1)$$

$$f = d_3 + d_2 + d_1 - b(s_3 + s_2 + s_1) - a(s_3^2 + s_2^2 + s_1^2).$$

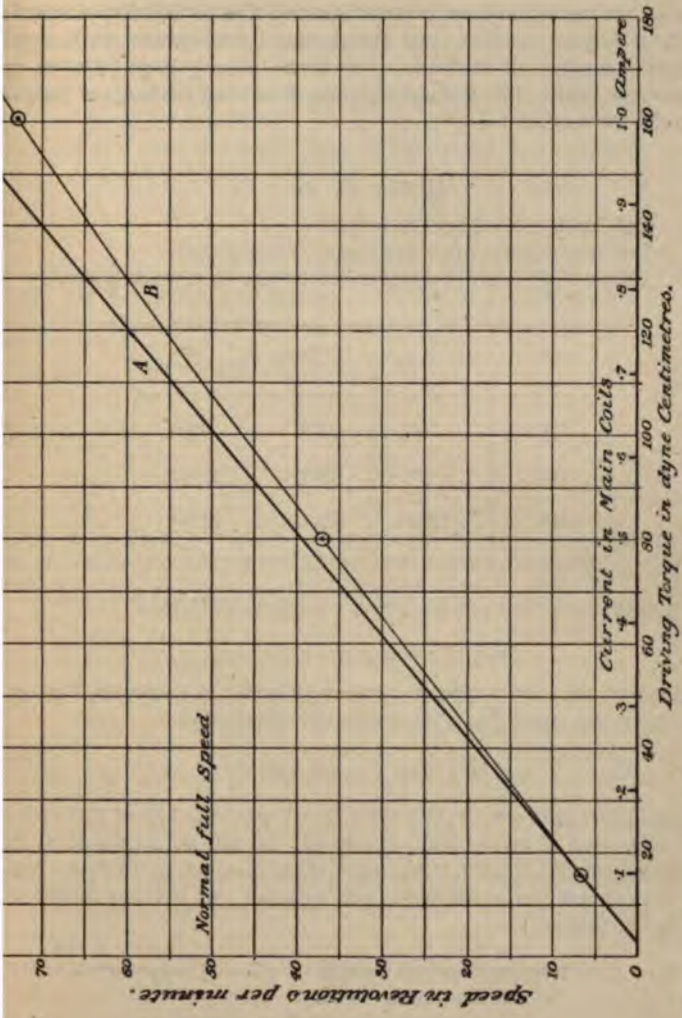


FIG. 13.—Torque-speed Curves for Meter No. 5 (effect of air friction exaggerated by use of a weak brake.

A. Curve drawn from equation $d = 3{\cdot}16 + 1{\cdot}95\ S$.
B. Curve drawn from equation $d = 3{\cdot}16 + 1{\cdot}95\ S + {\cdot}003\ S^2$.
⊙ Points determined by experiment.

The air friction of a rotating body is probably not exactly proportional to the square of the speed, but the formula is found to agree very closely with experiment.

An example of the effect of air friction is afforded by Meter No. 5, in which each of the two parts of the astatic armature is made up of four oblong coils wound on open "formers." Such an arrangement naturally fans the air, and experiment showed that air friction at speeds of from 40 to 50 revolutions per minute was by no means small compared with mechanical friction. The brake having been reduced to about one-sixteenth of its full strength, the following readings of torque and speed were taken :—

Meter No. 5.

Full-load, 100 volts × 10 amperes.
Full-load torque, 1610 dynes cm.; drop ·6 volt.
Effect of air friction exaggerated by use of a weak brake.

Volts.	Amperes.	d Dyne cms.	s Revs. per min.
100	·10	16·1	6·58
100	·50	80·5	37·40
100	1·00	161·0	72·60

By inserting these values in the above equations we find—

$$f = 3{\cdot}16\ ;\ b = 1{\cdot}95\ ;\ a = {\cdot}003.$$

The curve of the meter with its weakened brake is shown in Fig. 13, where the lower curve line is drawn to the equation—

$$d = 3{\cdot}16 + 1{\cdot}95\, s + {\cdot}003\, s^2,$$

while the upper curve (a straight line) shows what the law of this meter would have been if no air friction existed. It will be seen that at 80 revolutions per minute air friction amounts to as much as 19 dyne cms.

At full speed (50 revolutions per minute) the driving torque is expended as follows :—

In overcoming mechanical friction	...	3·2 dyne cms.
" " air friction... ...	...	7·5 " "
" " brake torque	...	97·8 " "
Total	...	108·5 " "

That is to say, with the weak brake air friction amounts to about 7 per cent. of the whole resistance to rotation. With the brake restored to its [illegible] strength the corresponding figures are—

Mechanical friction	3·2	dyne cms.
Air friction	7·5	" "
Brake (full strength)	1600·0	" "
Total	1610·7	

It will be seen that the air friction is now less than one-half per cent. of the total resistance, although this particular meter has less torque than the standard now adopted.

Another method of determining friction which seemed at first sight to offer several advantages is to run the meter at about full load, and having carefully determined the speed, at a given instant cut off the currents and note the time taken by the meter in coming to rest. If at any instant the angular velocity is ω, we have the equation—

$$I \frac{d\omega}{dt} = f + b\omega \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

where I is the moment of inertia of the meter axle and parts attached to it; f is the mechanical friction as before, but b now stands for brake torque at unit *angular* velocity. (1) gives the value—

$$t = \frac{I}{b} \int \frac{d\omega}{\frac{f}{b} + \omega},$$

hence

$$f = \frac{b\,\omega_1}{e^{\frac{tb}{I}} - 1} \quad . \quad . \quad . \quad . \qquad (2)$$

ω_1 being the initial angular velocity. The moment of inertia is easily determined by attaching a hair-spring, of known strength s, to the axle and observing the period of oscillation τ; then—

$$I = \frac{s\,\tau^2}{4\,\pi^2} .$$

s must be taken in dyne cms. per radian of torsion.

In practice this method has not given good results. A meter—especially a frictionless meter—comes to rest so gradually that it is exceedingly difficult to determine with exactness the instant when it stops. Again, if there is the least want of balance in the axle it will very rarely happen that the meter comes to rest at its position of stable equilibrium without first making one or more very slow oscillations about that point. Hence there are often very large discrepancies in successive observations, and on the whole the average time taken in coming to rest will be greater than it would be if the meter were perfectly balanced. Some early experiments with meter No. 2 may be quoted as an illustration of this uncertainty. Measured by the torque-speed curve the friction was 2·65 dyne cms.; the mean of two fairly good observations of the time of stopping gave the value 2·98 dyne cms. This result being considered encouraging, a large number of similar tests was made, with the result that the average of the whole series gave 1·27 dyne cms. as the friction. This figure is undoubtedly a *good deal lower than* the true value, and, except as a rough and

ready means of comparison, the stopping test has not since been employed. All the friction values given in the paper are deduced from torque-speed curves.

An improvement on the stopping test would be to record on a chronograph the times of successive revolutions of the meter, beginning as soon as the currents are cut off and ending a little before the meter comes to rest. The chronograph record would enable a time-speed curve to be plotted, and the slope of the curve would give the total retardation, from which the brake torque would have of course to be deducted in order to arrive at the value of friction.

Calculated Friction.

It is useful to compare the value of friction given by direct experiment with the value calculated on the assumption that the bearings are the sole cause of friction. This comparison has been made in the case of meter No. 2, and shows a considerable margin of friction unaccounted for.

If the diameter of contact between the steel point and the cup forming the step bearing were measurable, the friction moment could be estimated from the formula—

$$f = \frac{k\,P\,d}{3},$$

where

k is the coefficient of friction.
P „ total pressure on the bearing.
d „ diameter of contact.

It is, however, impossible to measure the contact diameter when the point and cup are spherical surfaces, and recourse was had to experiment. The total friction having been taken by the torque-speed method, a weight of about 50 grammes was added to the armature, and the friction again determined. The weight being removed, the first test was repeated. The result of these tests was to show that this particular point and jewel offered a frictional resistance of ·092 dyne cms. per gramme weight pressing on the jewel. Now before the meter started running on October 12, 1899, the pressure on the jewel was measured and found to be 12 grammes; hence the step-bearing friction would be $\cdot 092 \times 12 = 1\cdot 1$ dyne cms.

The friction added by each brush wheel is roughly as follows :—

Brush-wheel step bearing: pivot assumed to have a flat end in contact with flat step plate.

Weight of wheel and its axle, 1·2 grms.; or $P = 1{,}200$ dynes nearly enough.

Diameter of contact, say equal to diameter of pivot, namely ·035 cms.

Co-efficient of friction ·20.

Then using the formula—

$$f = \frac{k\,P\,d}{3}$$

ictional resistance of the bearing is 2·8 dyne cms.

The commutator wires press against the wheels and force the brush pivots against the sides of the holes in which they run. The mean pressure on each wheel is about 50 dynes, and the radius of the pivot being ·018 cms., the friction moment is roughly $50 \times \cdot 2 \times \cdot 018 = 1\cdot 8$ dyne cms. Adding this to the step friction and multiplying by 2 to include both brush wheels, we find they require a torque of nearly 6 dyne cms. applied to their own axles to overcome friction. This figure must of course be divided by 12—the ratio of the diameters of wheels and commutator—to give the frictional moment of the brush wheels upon the armature axle. That is to say, the brush wheels account for about ·5 dyne cms., while the meter axle bearing accounts for 1·1, making a total of 1·6 dyne cms. estimated friction.

The lowest observed friction in meter No. 2 was 2·1 dyne cms. (see Table IV., Oct. 12, 1899), so that, remembering that brush-wheel friction is an overestimate, there is at least ·5 dyne cms. unaccounted for. No doubt the rolling of the commutator wires on the brush wheels accounts for some of this, and there is also the work done in overcoming cohesion as the wires pull themselves off the wheels. This is a form of work which is probably not completely or even at all reversible, so that it is not given back when the wires come into contact with the wheels. There may also be a very small resistance to rotation due to hysteresis in the steel axle. The magnetic field of the brake magnets tends to produce a non-uniform distribution of induction at the surface of the axle, and if this want of uniform density extends to any depth below the surface, some part of the volume of steel will be going through two small magnetic cycles in each revolution of the axle.

TABLE I.

ERRORS OF UNCORRECTED MOTOR METER.

Maximum Driving Torque = 100, Friction = 2. Full Speed = 100; Arbitrary Units.

Driving Moment M.	Friction f.	Speed (numerically equal to $M - f$.	Percentage error.
2	2	0	inf.
4	”	2	— 50
10	”	8	” 20
20	”	18	” 10
40	”	38	” 5
60	”	58	” 3·3
80	”	78	” 2·5
100	”	98	” 2·0

Standard range = 1 to 3·3.

TABLE II.

Errors of Uncorrected "Frictionless" Meter.

Maximum Driving Torque = 100, Friction = ·02. Full Speed = 100; Arbitrary Units.

Driving Moment M.	Friction f.	Speed (numerically equal to $M - f$.)	Percentage error.
·02	·02	0	inf.
·04	·02	·02	50
·10	·02	·08	20
·40	·02	·38	5
1·00	·02	·98	2
10·00	·02	9·98	·02
50·00	·02	49·98	·04
100·00	·02	99·98	·02

Standard range = 1 to 250.

TABLE III.

Friction Tests * of Meter No. 1. This Meter was Started on May 25th, 1899, and has been Running at about 80 Revolutions per Minute continuously since that Date.

Date.	Total Revolutions of Armature Axle.	Moment of Frictional Resistance. (dyne cms.).
25th May, 1899	0	Not measured accurately, but about = 7 dyne cms.
28th June ,,	3,460,000	6·8
26th Sept., ,,	12,275,000	6·8
30th March, 1900	29,046,000	7·2

* For methods of measurement see Appendix.

TABLE IV.

FRICTION TESTS * OF METER NO. 2. THIS METER WAS STARTED ON OCTOBER 12TH, 1899, AND HAS BEEN RUNNING AT ABOUT 57 REVOLUTIONS PER MINUTE CONTINUOUSLY SINCE THAT DATE.

Date.	Total Revolutions of Meter Axle.	Moment of Frictional Resistance (dyne cms.).
12th Oct., 1899	0	3·2
" " "	100	2·1
13th " "	not noted	2·3
16th " "	not noted	2·4
20th " "	not noted	3·2
7th Nov. "	2,088,000	2·9
20th " "	3,080,000	3·0
21st Dec. "	4,313,000	2·9
29th Jan., 1900		3·3†
30th " "	7,233,000	3·5‡

* For methods of measurement see Appendix.

† Commutator observed to be making irregular contact. After making test, examination showed a fine hair wound round and entangled in commutator. The hair was removed as carefully as possible without taking the meter to pieces.

‡ Taken immediately after removal of the hair.

The PRESIDENT: I am delighted to find that among those present we have the company of a distinguished American electrical engineer, whom I ought not, perhaps, to call an American because we may claim him as an Englishman born; I mean Mr. T. Lockwood, of the Bell Telephone Company of Boston, who has had the honour of being President of the American Institute. I will ask him to open the discussion by contributing anything he chooses to say on this subject, or on any other that may occur to him.

Mr. T. D. LOCKWOOD: I am somewhat surprised at this my first meeting with you to find that the *personnel* of the Meeting is very much like that of the Meetings which I am accustomed to attend in New York,—there is such a large percentage of young faces. I have, perhaps, been a member of this Institution longer than most of those present, and yet Mr. Lockwood.

kwood. this is the first time that I have had the pleasure and privilege of being present to listen to a paper and to take part in the discussion on the paper, or, as your President has kindly remarked, to discuss anything else. I esteem it a very great privilege to be here this evening. It was not until this afternoon that I knew there was to be a Meeting of the Institution of Electrical Engineers, and when I was handed the paper of this evening to which I have listened with such great pleasure, I must confess that I was somewhat disconcerted at the title. This was, of course, before I read the preamble of the author, for it did seem to me that I was approaching, within very close limits, to what the author so very carefully and promptly disclaimed, perpetual motion. But after hearing what he had to say, and after carefully looking myself at the diagrams and reading the paper, I can only add this, that I am sorry that in the Proceedings of our Societies it is impossible to reproduce experiments, or the manner of the speaker, or to reproduce anything except the dry text sometimes—not this time, however—of a dry paper.

The difficulty which Mr. Evershed remarked, of learning what had been done before, is one which I apprehend has occurred to most of us. I, perhaps, have read as many old patent specifications, British and American, and others, many in foreign languages, some written in English which might as well have been in a foreign language, as any one; and I have, myself, to the fullest extent, appreciated the great difficulty of learning anything from 99 out of 100 of those specifications. If the picture was all right, the text was all wrong, and if the text was all right the picture did not agree with it as a rule, so that it was very difficult to understand what the inventor or the *quasi*-inventor was attempting to explain.

The author said that he did not know until he was far advanced in the production of his meter, that anything on the same lines in which he had been going had been done before. That, of course, is not at all an unusual experience, it is perfectly familiar to any one of us who has done any inventing at all; and I am reminded very forcibly of a remark which I found once in the preface of the first book which was ever written on electric lighting perhaps, viz., the book of Hippolyte-Fontaine,—"People of old times had very little honesty; they have stolen all our best inventions."

r. rranti. Mr. S. Z. de Ferranti: I can quite understand what Mr. Evershed said when he told us that he had worked for ten years on this subject. If he had said that he had worked at it for longer than that, were it not for his age, I should not have been at all surprised. No one who has not worked at this sort of thing can have any idea of what it involves in the way of time, the number of disappointments, and the amount of work which is done, which appears to be fruitless, and the very long time it takes to make anything commercially useful. It would be quite superfluous on my part to say how exceedingly interesting the paper has been, or to compliment Mr. Evershed upon the most beautiful mechanical contrivance, and the perfection of the details which he has worked out. He has, unfortunately, as he told you, found out that other people have had som[illegible] the same sort of ideas. It is an experience that every-

body is subject to, and I am beginning to think now that if I do make anything in the nature of an invention, half-a-dozen people have probably done it before me. With regard to the particular subject of the paper, viz., a frictionless meter, I do not think perhaps that Mr. Evershed has appreciated how frictionless some other meters have actually been. I remember when working a great many years ago, I think it was in 1885, when I had a small works in Hatton Garden, that I was struck with a very curious occurrence which happened to one of the meters which I made there. I thought I had discovered, or at any rate come face to face with, some marvellous new circumstance or thing which was quite beyond my comprehension. One day when the current was turned off, one of my mercury meters, which I may say was very frictionless, rotated without any connection with the electric circuit, and rotated backwards. This was exceedingly surprising. We watched it very carefully, and the meter moved slowly backwards for two days. We discovered eventually that the sixth or seventh wheel of the meter was jammed, and that the spring in the train of wheels was sufficient to give driving power to run that meter at an exceedingly slow speed for two days. I should like to ask Mr. Evershed—I do not know how he does it in his meter—to calculate what the friction or resistance of that meter was in order that it should go round at all against its own friction for two days with such a class of driving force. Another point is this. We find that a mercury meter constructed to register up to 300 amperes starts with certainty with 0·1 of an ampere or 1-3,000th part of its normal full-load current. Now that is not a 3,000th part of the power, but it is simply a 3,000th part of the current: although when you come to think of what the friction must be in that case, notwithstanding the residual magnetism which helps to start the meter, you will find that the internal friction of such an apparatus must be exceedingly small, and I should not like to put it down at any fixed amount. I will mention another curious fact. It is very important in this particular class of meter which we make, that the little fan which is immersed in the mercury should be perfectly balanced, and we take elaborate precautions that it should be so, because if it is not balanced and the meter is a little out of level, it interferes with the starting; yet such forces are very small. I have had a certain amount of difficulty (quite unaccountable at first) with meters in starting properly, through this want of balance, although the meter had been carefully balanced, and we eventually found that quite a serious source of trouble in this direction arose from varnishing and lacquering the small fan immersed in the mercury more thickly on one side than on the other, and so displacing a tiny quantity of mercury more on one side than on the other and putting the meter out of balance in mercury. There, again, it is quite evident that forces minute in their dimensions must be at work to produce any of these results. Mr. Ferranti.

I should like to point out that the Aron meter practically disregards friction, although there is a train of wheels there. The principle of the meter is such that it does not matter, and there are other meters of that kind, but it has one objection amongst many others: it ticks. I should recommend Mr. Evershed very closely to consider some other of his beautiful arrangements (which he appears so easily to find out

for overcoming all difficulties) to stop the noise of that meter so that it should not have the same disadvantage as the one I have mentioned. With regard to the meters to which I have referred and in connection with which I have done work myself, all of them are, practically speaking, frictionless on the pivots, because they are a compound balance in air and mercury, and I do not think the friction due to the pivots is probably any greater than that of the bottom pivot in Mr. Evershed's meter. Mr. Evershed has been good enough to mention that I have had something to do with what is an essential feature in his meter, viz., the magnetic suspension, and that is so, and I cannot help referring, as it is the only record, to a Blue Book on the subject, which shows several very bad forms of magnetic suspensions for the armature of a meter. But there just happens to be one good form amongst the bad ones, which has a concentric suspension and which does not pull sideways; in fact it appears to embody the same principles as the successful suspension which Mr. Evershed has adopted. With regard to the commutator, it is exceedingly pretty: the nearest approximation there has been to it is the commutator devised by Lord Kelvin, in which the commutator parts were rigid, but the brushes were flexible spring circles. I am afraid that is rather a poor definition of it. The brushes were made up with a number of discs with the edges turned up, and these edges split, which pressed against the commutator and so formed a flexible electrical contact with the commutator. Of course that was not the improvement in these days that was wanted in commutators. It was necessary to make the conditions of the machine such that it would commutate sparklessly without devices of that kind. I only remember seeing it running once, and that was in Lord Kelvin's laboratory.

My own idea about this whole subject—without wishing to detract in any way from the most beautiful work Mr. Evershed has done—is that the meter is greater in scientific merit perhaps than in commercial value. Of course it is only a conjecture, but what I have found in hard practice, having to satisfy all sorts of people wanting electricity meters, is that they will ask for the most absolute simplicity, and if they can get that perfect simplicity they will sacrifice a good deal for it. I therefore think that Mr. Evershed has quite a task before him in introducing anything, no matter how perfect, that involves the various parts that are shown in this very beautiful instrument of his. I hope that anything I have said will not detract in any way from the splendid work which Mr. Evershed has done.

Wood.

Mr. REGINALD WOOD: I am afraid, after the remarks of the last two speakers, I shall appear rather ungracious, but the fact is I have come down here expressly to say that I claim to be the inventor of this magnetic suspension exactly as it is shown. It is rather an unpleasant thing to have to say, because when one reads the paper one cannot help admiring not only the language of the paper but the law of the instrument. I agree with Mr. Ferranti that the commutator is beautiful, and the electro-magnetic connection between the shaft and the train-gear is also a very beautiful contrivance. I have nothing but congratulation to offer Mr. Evershed. Of course I must say what I want to say, viz.,

that I make my claim, but I do not want it to be considered to be made in an ungracious manner, although I am afraid it is. Mr. Wood.

[*Communicated.*] A description of my magnetic suspension will be found in Patent Specification 18,053 of 1896. The question of "floatation" of a magnetically suspended shaft presents an interesting point. If all the forces are accurately balanced, the inertia of the rotating body causes it to "float" when the speed is sufficiently high. My attention was given to magnetic suspension, because I thought it highly desirable to abolish friction and all chance of hot bearings in my Feeder Machines, which are described in the Journal, vol. xxvii., p. 637; and I am indebted to the author for proving the truth of my prediction. If some one will now utilise my method of applying magnetic force to neutralise centrifugal force, a considerable advance may be made in economising fuel. Many of these matters are worthy the attention of the Associated Railways.

Mr. W. M. Mordey said that he agreed with Mr. Ferranti as to the importance of simplicity in meters. Although he admired the way the Evershed meter had been worked out, he could not help thinking that commutators were objectionable in meters. The greatest simplicity Mr. Mordey.

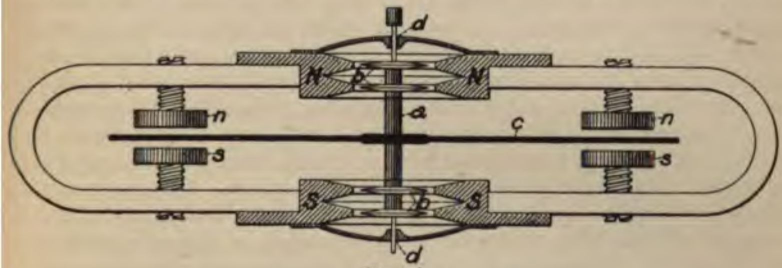


FIG. A.

was got by mercury meters for direct currents and induction motor meters for alternate currents. But the Evershed instrument was a beautiful example of commutator meters, and shared with the Thomson meter the useful quality of being suitable for all sorts of circuits—for direct currents, and for alternate currents of any periodicity. For alternate currents it should be good even with low power-factors. The very small values given for friction were very interesting, but none the less all meters were very disappointing as regards efficiency. Probably no meter takes so little as one watt, and yet one watt means about 44 foot-pounds per minute. He wished to supplement the author's reference to the Stanley meter by showing them an example of the magnetic suspension sent him by his friend Mr. Stanley, in whose laboratory in the United States he had seen and tested the first instrument produced. He thought the author hardly realised what a very pretty thing the suspension was—it was practically frictionless, and entirely avoided the troubles due to vibration from alternate currents.

He then sketched a diagram (Fig. A) of the Stanley arrangement showing that the iron shaft *a* was magnetically supported by the flux *passing into the flanges b* from the encircling poles N and S—the disc c

Mr. Mordey. mounted on the shaft *a* being magnetically braked by passing through the field between the polar extensions *n s*. This method of suspension caused the shaft and disc to float in the air. Extensions of the shaft passed through guide holes at *d d*, but there was no pivot in the ordinary sense. It would be seen that friction could only take place at *d d*, and that a fair amount of clearance in the magnetic gaps and good mechanical centreing would make this friction negligible. Mr. Stanley had told him, in fact, that some of his 6 k.w. meters started with 2½ watts.

Mr. Boot. Mr. H. L. BOOT: As a user of meters, and as one who has had considerable trouble with meters, I am glad to be able to inform the manufacturers of meters of the difficulties we have to contend with. I think perhaps many engineers do not appreciate the financial value to a works in using a good meter. During six years' experience of different types of meters I have had to scrap no less than two types, and I have also found that it has paid me to do so. With regard to the first type I had, the consumers patted me on the back because it would not register; with regard to the second type, the consumers swore at me because it registered too freely; and with regard to a third type the consumers considered that we were always sending people to examine the meters and to push on the dials. The essentials for a meter are: First, it must be accurate; secondly, it should be able to stand rough usage; thirdly, it should not be affected by vibration; and fourthly, it should not run backwards and forwards on its own initiative, but should be controlled as it is intended to be. Moreover, it should be able to withstand the overloads that are sure to occur, due to short-circuits, which I have found in many instances to have a serious effect on the accuracy afterwards, especially in the case of magnetic meters. The meter also should be simple. I admire Mr. Evershed's meter immensely. The amount of labour that must have been expended in designing such a beautiful meter is apparent to every one, but at the same time I would personally prefer a meter which I can, to a certain extent, understand, and know how to alter and adjust, and which does not depend so much on permanent magnets.

Mr. Ferranti mentioned the fact of a meter ticking. It is perfectly true that Aron meters tick, and it is unfortunately true that nearly all types of meters with alternating circuits give considerable trouble owing to the noise they make. I have designed a little arrangement something of the form of a relay, which cuts out the meter during the hours it is not being used. In many instances I have found this relay give great satisfaction to consumers who object to the noise of a meter during the hours when it is not being used for light. Another point I notice Mr. Evershed has studied very carefully is the elimination of friction. I was going to mention, although it has already been mentioned, that in the Aron meter this is already provided for, as it is not taken into account. The last point I would impress upon the makers of meters is that we require rapid delivery.

Mr. Schattner. Mr. E. B. SCHATTNER: The meter designed by Mr. Evershed seems to me very ingenious in every way, but my experience shows me that it is hardly simple enough, and I should say it could not be produced at a price at which a meter nowadays ought to be produced. It

seems to me that since the re-advent of electrolytic meters, which are considerably simpler, and consequently less expensive, than other meters, prices have generally been reduced, and the tendency has been everywhere to produce a less expensive motor meter, even at the sacrifice of accuracy. Mr. Schattner.

Professor W. E. AYRTON: In his opening remarks, Mr. Evershed takes me back to a period of eighteen years ago, a period to which my attention has been very much directed during the last few days at the Law Courts. At that time, as you have been told, I first thought, with my colleague Professor Perry, of the right principles of meter construction which have been enumerated this evening, but I certainly did not expect to see what may be called a "dream" of a meter, where the ideal has been brought to absolute perfection, to see in practice what one merely aimed at, namely, to get a perfect straight line law, to get the resisting force from all causes, including brush friction, friction of the counting mechanism, friction of pivots, and also the proper magnetic resistance proportioned to the velocity, combined with what is much more easy, a driving force proportional to the power. It has been said this evening, and perhaps it might appear at first sight to be justifiable, in the criticisms, that Mr. Evershed has only attained this result by the use of great complexity. Well, another inventor whose name has also been quoted, has, with the clock-meter, achieved our other ideal, and obtained marvellous results and accuracy by the employment of great complexity. If you take the present Aron meter (which is selling in thousands per year even in this country, backward as we are in electric lighting, and in even greater numbers abroad) and think of its complexity, but on the other hand think of its accuracy and compare it with our original gaining clock, which was shown in this room some eighteen years ago with its single pendulum, you would have said at once that that original clock would have been the one to be sold in thousands, and that the Aron meter of to-day, if you could have seen it, would have had no chance whatever. It is just the other way. That meter, simple as it was, had no sale; the Aron meter of to-day, with its electric mechanism for winding up, its device for shifting over the counting mechanism and for altering the direction of the current in the two coils every eleven minutes, and with the noise it makes in winding up every half-minute, sells in thousands. It is not, however, the mere ticking, but the gurgle of the present Aron meter which is objected to. Be that as it may, you have only to look at the value of the shares and the dividends paid by the Aron Company to see what delightful results can be attained when you have, complexity it may be, but complexity extremely well worked out. Professor Ayrton.

Look, for instance, at Alfred the Great's candle, the original clock, and then look at a modern clock, or at your own watch; what chance have watches? A mere theorist might object: They are far too complicated, nobody will buy them! So that in case Mr. Evershed should have the smallest feeling of despondency because he has obtained this marvellous accuracy with a certain amount of complexity, I may say let him bear up; there is a possibility that his meter may rival, say, the Waterbury watch with its sale, and I have no doubt that he will then be quite satisfied.

Professor Ayrton.

It has been said that the Aron meter is a frictionless meter. I do not know what that has to do with the paper, which is on a frictionless motor meter. The Aron meter is neither a motor meter, nor is it by any means frictionless, but it is merely one in which the friction does not produce an error in the reading. There are other meters with various devices aimed at preventing the friction from producing much error in the reading—for example, the well-known starting coil in the Elihu Thomson meter. But what Mr. Evershed has succeeded in doing is to get a meter which shall not require any of these devices, and which shall still have an accuracy of a very high order. It is not quite right to say that those others are frictionless meters, because their readings are, to some extent, independent of friction. They have attained these results by certain devices: Mr. Evershed has obtained it by annihilating the friction.

We were all most interested to hear what Mr. Evershed told us about the range, and the small friction of his meter. I do not know at all whether Mr. Evershed by chance has tested the friction in the Ferranti meter; if so, we should all like to hear what the value may be. Mr. Ferranti has, I think, a certain device, namely, the permanent magnet, which assists in starting his meters. It is not quite fair, therefore, to say that because you have a meter with a starting coil, or a certain device, and you are thereby enabled to start with a certain fraction of the full load, therefore there is little friction. It does not follow; there may be much friction. But what Mr. Evershed tells you, practically, is, that with no device to help the meter going round, or to compensate for friction, he has, by not allowing friction to be introduced, obtained those wonderful curves, in which the whole error in measuring from the power at which the meter starts up to 5,000 times that power is only 2 or 3 per cent. That result is most amazing.

One other point was spoken of with regard to the Aron meter which has delighted me very much; namely, that Dr. Aron, during the last two or three years, has gone back to the original idea—I am not speaking merely of the clock now—that Professor Perry and I put forth, and the idea that Mr. Evershed has utilised, namely, to measure what you pay for; not to measure it indirectly, but to measure really what you pay for. Now, what do you pay for? You pay for units of energy. Dr. Aron has abandoned absolutely, as far as I know, meters to measure the quantity of electricity. All his early clock meters were quantity meters; all his modern meters, to which I referred as selling in thousands per year throughout the world, are energy meters. In the same way, Mr. Evershed has made an energy meter, and for that alone I desire to compliment him, apart altogether—it is a very large exception—from the ingenuity and the success with which he has not only introduced one little improvement, but has taken the whole energy meter and has invented, or re-invented, every single part of it to obtain perfection. In addition to all that, the fact that he has made an energy meter and not a quantity meter is to me the subject of great pleasure; and for that also I wish to thank him.

Mr. Lockwood.

Mr. T. D. Lockwood: I should like to crave your indulgence for a moment. On the very last occasion on which I had the honour to

preside at a meeting of the American Institute of Electrical Engineers, the subject of the paper was "Electric Motor Meters." It was a very able paper, but the author was rather disconcerted at the end of the meeting by finding that the very same objections with regard to complexity were made which I have heard made this evening. For this reason I feel like tendering my personal thanks to Professor Ayrton for his very able defence of complexity when complexity is accompanied by effectiveness. Mr. Lockwood.

Mr. ARON: I should like to confirm Professor Ayrton's statement that the meter as we turn it out to-day is an energy meter. I should also like to meet Mr. Boot and Mr. Ferranti with regard to noise. It is rather satisfactory to us that the only objection that can be raised against our instrument is that small one about the noise. It seems to me that it is rather hypercritical for a consumer who wants an accurate measure to raise a point about the noise in the instrument. As far as this country is concerned, I do not think we have had it seriously brought before us except in the case of alternating-current circuits, where in the winding gears we have had some slight trouble in arranging and adjusting the exact periodicities of which there are so many in use in this country. Under these circumstances we have found it necessary to do a certain amount of work in order to produce an instrument which will not make a noise when winding up, that is to say, that will not make a noise loud enough to be heard when the case is on the instrument. Hence I think Mr. Evershed need not trouble himself about the very perfect instrument that he has made as regards the noise, because if that is the only point, I can assure him that out of the thousands of meters we make and sell in this country there is but a very small number of cases where the question of noise is raised. Mr. Aron.

Mr. W. H. EVERETT [*communicated*]: Much ingenuity and skill is shown in the design of this meter, and the friction obtained is remarkably low. It is to be hoped, however, that some substitute may be found for iridio-platinum, if the meter is ever to be made by the thousand. Mr. Everett.

I would suggest that the main coil will give the strongest torque if each half of the coil is wound in the shape of a slice (parallel to the axis) of a hollow cylinder, so as to fit closely round part of the surface of the rotating drum. The two halves would, of course, be placed one on either side of the axle. The field of cylindrical coils, referred to in the Appendix, is a subject which I discussed some time ago in a comparatively simple way, *without* spherical harmonics.[1] In a coil such as shown in Fig. 7, the field close to the inner surface of the winding is about double that at the centre; which shows the reason for the suggestion made above.

I hope the meter is supplied with a case that is dust-tight. This is a weak point in several meters. The alternate heating and cooling draws in fresh air continually, and consequently dust, unless this is excluded by the aid of cotton-wool or baize, or otherwise.

The curves in Fig. 12 show extraordinary constancy and uniformity, such as are rarely met with in meters of the best-known types.

[1] *Electrical Engineer*, Jan. 8, 1897.

The President.

The PRESIDENT: The time has come when we must adjourn, and therefore I now ask Mr. Evershed to reply to the criticisms that have been made. I will merely interpose one word, and that is to add to the congratulations which have been offered to him on this paper. It obviously represents a very large amount of very careful thought, of much experimenting, and of great care and attention. In offering our congratulations to Mr. Evershed, I think we may honestly wish that those efforts may be crowned with material success. One word more about the criticism as to noise. As a consumer of electricity, I have in my house a meter which is one of those which makes ticks, and I am rather glad it is so, because walking across my basement hall at the dead of night as I lock up before I go to bed, I hear that meter tick, or if I do not hear it tick I know something is wrong, and I look at the reading to see how many hundred pounds my meter has charged against me since it was last read. There is some advantage, as I have found, in having a meter which ticks.

Mr. Evershed.

Mr. S. EVERSHED, in reply, said: I greatly appreciate the cordial reception accorded to my paper, and I am particularly sensible of the kindness with which Mr. Ferranti, Mr. Aron, and others have spoken of my work.

Mr. Ferranti made some interesting remarks about his meter and gave an example of its frictionless behaviour. I hardly think he could have expected us to calculate the friction movement from the data he gave, and in the absence of any precise figures with regard to the friction moment and driving torque in the Ferranti meter it is impossible to say whether it deserves to be called "frictionless." At all events it seems to require an initial torque to start it, this being provided either by a permanent magnet, residual magnetism, or a shunt circuit winding. I gather therefrom that the friction is not negligible.

Inventors have a way of working in the dark as regards possible forerunners in the same field, and hence it was that only after the completion of my first successful meter with a magnetically suspended and pivoted axle did it occur to me to hunt up the records and ascertain what had been done by others. It was then that I discovered how Mr. Ferranti had years ago patented various devices for suspending the axles of meters. Of these devices Mr. Ferranti has very frankly told us several were very bad forms for suspending the armature of a meter, but that one among them was concentric and therefore good. I hope Mr. Ferranti will forgive me for being equally candid and agreeing with him in everything he said excepting only in this—I cannot make an exception in favour of his concentric suspension. That also is bad as a suspension for a meter axle, although quite possibly good as a suspension for the shafts of heavier machines.

It seems to be generally agreed, among those speakers who represent rival meters, that, however perfect my meter may be as a piece of mechanism—whatever degree of accuracy may be attained by means of that perfection—the frictionless meter introduced to you this evening is too complicated for everyday use. Now I do not think I could possibly put the advantages and disadvantages of complication before you more clearly, certainly not more picturesquely, than Professor Ayrton has

Mr. Evershed.

done. Mr. Lockwood did well to draw our special attention to the value of Professor Ayrton's remarks in defence of "complexity when accompanied by effectiveness." That is really the sole criterion of the merit of any mechanism—its effectiveness. What is effectiveness in a meter? It seems to me that to be effective a meter should be accurate, and that it should run for many years without attention. Now I was told quite recently by one station engineer that the meters at present in use require overhauling and testing about once a year. Another engineer to whom I mentioned this experience said, "If it were only *once* a year I would not mind so much." If that is a true indication of the behaviour of the average meter in use to-day, it does seem to me that some improvement is needed. In my meter I have secured abundant accuracy by relieving the motor of every duty save one. It simply has to overcome the torque of the brake, hence it always revolves at the right speed. It has nothing to do with the counting train. Then, again, the reciprocating lever has only to drive the train. So long as it has enough force to do this the train must register correctly. The lever and train have absolutely no influence on the speed of the meter. Hence there are in my meter two distinct mechanisms each of a simple character, each having one and only one function to perform. In that way an accuracy has been attained which has never been reached by any previous motor meter. But at the same time another equally important end has been secured. The reduction of mechanical friction has so enormously diminished wear and tear that one may reasonably expect the "frictionless" meter to run from 5 to 15 years without any adjustment or attention. Mr. Boot has told us that engineers do not sufficiently appreciate the financial value of a good meter. Perhaps it will help us to a proper appreciation if I mention that in the case of two types of motor meter at present largely used the makers actually state in the instructions sent out with the meters that the commutator should be carefully cleaned and the brushes adjusted every time the meter is visited for the purpose of reading the indices. In the case of one of these meters it is also recommended that at the same time the jewel in the step-bearing should be removed and examined. In one meter the commutator and step-bearing are actually arranged outside the meter case in order to facilitate these frequent examinations and adjustments. These would, no doubt, be called simple meters, but what is the financial value of their simplicity? The financial value of simplicity may be negative, as it clearly was in the case of Alfred the Great's candle.

Of course complication influences cost to some extent; but that is a matter which concerns the manufacturer alone. If he can make the meter and sell it at a reasonable price, surely the user need not trouble himself about the cost of complexity. His sole concern is with the effectiveness of the mechanism.

Several speakers have referred to the ticking of meters. The reciprocating lever in my meter makes a tick every time it strikes the stops which limit its stroke. These stops are brass pins, and naturally the ticking is audible when, as in the meter on the table, the case has been removed in order that you may examine the works. With rubber

Mr. Evershed.

or leather stops the ticking is quite inaudible. Of course the ticking ceases when the load is cut off, so that a nervous consumer would be in no danger of sleepless nights. In this respect my meter differs from the Aron meter, in which the ticking of the two pendulums goes on day and night, load or no load, and there is in addition an intermittent convulsive click due to the self-winding gear. When attempting to test the accuracy of an Aron meter by counting the number of beats one pendulum makes in excess of the other in a given time, I found this click of the winding gear peculiarly distracting; so much so that, in despair, I gave up testing the meter at light loads. I made a test at full load, found the meter was accurate and assumed it must be so at any smaller load. I have no doubt whatever that it was, since it is a meter with a definite law.

The Stanley meter interested me from the moment my attention was drawn to it by the Examiner of the United States Patent Office, and I was very glad to hear Mr. Mordey's remarks upon it, although I could not help regretting that he did not give us some facts and figures as well as generalities. Of course one knows that the Stanley meter is "very nearly frictionless." All motor meters are—so their makers say. I wish Mr. Mordey could have told us what the friction actually is in the Stanley meter, and what ratio it bears to the driving torque. We should then have been in a position to estimate its accuracy at any load. Mr. Mordey also forgot to tell us how much power is spent in the pressure circuit of the meter and what voltage drop there is over the main current coils at full load—details which are essential if we are comparing one meter with another.

Mr. Mordey believes in mercury meters for direct currents and induction motor meters for alternate currents. I cannot altogether agree with him there. Mercury as a means of leading current to the rotary part of a meter has many drawbacks besides the excessive friction it introduces. For alternate-current work the induction motor has many advantages, no doubt, but as a motor for a meter most of its characteristic advantages tend to vanish. Of course the absence of a commutator is a rather attractive virtue, but even this is only purchased at the expense of something else. As every one knows, it is of great importance that an alternate-current meter should correctly register the work done both on non-inductive and inductive loads. It should also be as nearly as possible independent of frequency. To secure this in an induction motor meter, the field due to the pressure circuit must be as nearly as possible a quarter period behind the field due to the main current. Hence we find makers either use a laminated iron core electromagnet to give the pressure field, or coreless copper coils in series with an iron-cored choking coil to secure the required difference in phase; in either case there is a constant waste of power in the iron core in addition to the C^2R waste in the exciting coils. To secure sufficient phase difference the pressure circuit must be wound so that the quantity pL is at least ten times the ohmic resistance. Assuming this ratio, the power-factor of the pressure circuit itself will be about ·10, so that the pressure current will amount to ·10 ampere for each watt wasted in C^2R and hysteresis in the pressure circuit when on a 100-volt circuit. This

Mr. Evershed.

necessitates a large amount of copper in the windings in order to keep down the C^2R loss, and I doubt if any induction motor meter has yet been made with so small a constant pressure circuit loss as 1 watt. As a rule, the core loss and C^2R loss together will be found to amount to 3 or 4 watts if not more, and to this must be added the C^2R loss in the armature due to the current generated by the pressure field—a loss which is of course always going on.

Assuming the waste can be brought as low as 2 watts, the current taken by the pressure circuit will be ·20 ampere as against ·01 ampere for the "frictionless" meter. Imagine a high-tension alternate-current station supplying at 1,000 volts. For each 1,000 induction motor meters on their mains there will be a day and night output of 20 amperes, as against 1 ampere if "frictionless" motor meters are in use.

The only alternative to excessive waste in the pressure circuit of an induction motor meter is to cut down the pressure field and obtain the required driving torque by increasing the turns on the main current coils. This, of course, only leads to a new trouble, namely, excessive voltage drop at full load. One of the early makers of this type of meter had the hardihood to assert that, although there was a large drop in his meter, it was all due to the self-induction of the current coils, and therefore did not reduce the volts on the lamps!

As an example of the indifference of meter makers to such an important point as the voltage drop, I may mention that in one of the best known alternate-current meters in the market the drop at full load is as much as 5·7 volts at 100 periods, and over 3 volts at 50 periods. I obtained these figures by actual measurements made upon a 100-volt 10-ampere meter.

Mr. Schattner very naturally contrasts the apparent complexity of my meter with the apparent simplicity of his own electrolytic meter. It is true that an electrolytic meter looks very simple, but this is, I think, due to the evasion of many problems we meter makers are engaged in solving. An electrolytic meter cannot be sealed up and delivered to the supply station ready for use. It requires far more constant attention than even defective motor meters, and even with skilled attention it is liable to be very messy. The cost of all this attention and upkeep must be capitalised and added to the prime cost before we can say it is a cheap meter.

The arrangement of the main coils which is suggested by Mr. Everett in his communication is the one actually used in the meter, but in Fig. 7 the two front bobbins are removed in order to show the armature. This, no doubt, led Mr. Everett to suppose that I was only placing current coils on one side of the armature.

The method of calculating the field of coils which Mr. Everett described in 1897 is a very useful one when an accurate estimate is essential, but what one usually requires is a rough approximation which can be arrived at in five minutes, and I hardly think Mr. Everett's method, ingenious as it is, is sufficiently simple for everyday use.

Before I sit down I desire to thank Mr. Ewart, who prepared the drawings which are reproduced in the paper and also the diagrams on the wall. Mr. Ewart's masterpiece hangs over there on the wall, where

Mr. Evershed.

it presents a rather pleasing contrast with the masterpiece above it. I am also indebted to Mr. Mather and Mr. Duddell, though I do not know in what proportion I am indebted to those gentlemen for sending me this most beautiful arc-lamp with which I was able to show you the frictionless behaviour of No. 2 meter.

You will find a note sandwiched in between the end of the paper and the beginning of the appendices, in which I have endeavoured to express the obligation I am under to Mr. Cox, who has charge of the experimental department at Woodfield Works. That note barely expresses my indebtedness. When two people have been working together as Mr. Cox and I have been upon the meter for the last three or four years, it is very difficult indeed for them to divide the responsibility for the result of their labours. Any credit there may be attached to the design of the meter must be shared between us. I do not see my way to divide it in any way, and I hope you will not do so either. I should like to draw attention to this, that when we found that the ordinary commutator with brushes needed some alteration in order to make it good and serviceable in the meter, it so happened that I was working with elastic roller-brushes applied to the generator used in a certain testing set with which you are probably familiar. I have a sample of the new generator here on the table, fitted with elastic roller-brushes. These brushes worked so admirably that it occurred to me that we ought to be able to apply a similar kind of roller-brush to the meter, and I set Mr. Cox to work to make some very light elastic rollers and apply them to the commutator of the meter. I found Mr. Cox one day very unhappy, because he could not make the elastic roller light enough. He said, "Let me make a rigid roller, and make the commutator elastic." I thought that would do; anyhow, we would try it. We have never tried anything else, and I do not suppose we ever shall. The idea is simply perfection. That is really due to Mr. Cox's fertility of resource, and I am very glad to see that it pleased several of the speakers. I am sure that you will all admire it when you see it working in the meter.

I think I have now touched upon all the points raised in the discussion, and I have once more to thank you for the reception you have given to the paper.

The President.

The PRESIDENT: I now ask you to pass a hearty vote of thanks to Mr. Evershed for his most admirable paper.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Associate Members:

Edward Winram Dickinson.	John James Mann.
Ernest Albert Ellicott.	George Prescott.

Associates:

James Young Fletcher.
Joseph Rayner Gibson.
Edgar Green.
Henri L. Joly.
Ernest R. Matthews, C.E., F.G.S.
Albert Ernest Preston.
S. R. A. Wood.

Students:

George Bewsey Dyke.
Frank Herbert Fitt.
Ernest Lloyd Hocking.
Frederick John Holmes.
Richard Arnaud Kennedy.
Henry Felix Northcote.

The Three Hundred and Forty-ninth Ordinary General Meeting of the Institution was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, on Thursday evening, May 17th, 1900, Professor SILVANUS P. THOMPSON, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on May 10th, 1900, were read and confirmed.

The names of new candidates for election into the Institution were announced, and ordered to be suspended.

The following transfer was announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Henry J. Rogers.

The PRESIDENT: In addition to the transfer which has been announced, there is now to be read another and somewhat long list of transfers, being the completion of the incorporation into our own body of the members of all grades of the late Northern Society of Electrical Engineers. This is the final act, if I may call it so, of that movement which brings now to us such a gratifying increase of our members, and strengthens our hands in the district in and around Manchester. It is a matter of great congratulation to the Council that this incorporation should have been carried through, and we feel we owe a distinct debt of gratitude to the Officers, the Council, and the Hon. Secretary of the Northern Society, who have co-operated with us in such a satisfactory and cordial way in smoothing over all the difficulties which otherwise might have occurred, pulling together with us, and enabling us to bring to a conclusion this somewhat delicate negotiation. The Council has accepted the transfers of a considerable number of names into the various grades, and there remain only a few more names to be brought up on some subsequent occasion, names which, for reasons I need not go into, have been left for a future decision. I think there are about a dozen names yet to come up, but the great body of the membership is now transferred as you will hear. The list adds to our member-

ship now actually on the register 66 additional names, and I believe there are several more to come.

The Secretary then read the list of names as follows :—

MEMBERS OF THE NORTHERN SOCIETY OF ELECTRICAL ENGINEERS TRANSFERRED.

To the Class of Members :—

J. B. Atherton.
A. R. Bellamy.
A. B. Blackburn.
Thomas Browett.
James Connolly.
John T. Connolly.
J. F. L. Crosland.
G. St. John Day.
Frederick Charles Gibbons.
Joseph Platt Hall.
Tom Hawkins.
George Hill.
William Lawrie.
Herbert Lindley.
Robert Matthews.
Charles S. Northcote.
A. B. Pescatore.
T. L. Pescatore.
Montague Tabor Pickstone.
Roland S. Portheim.
Percy Rosling.
Godfrey B. Samuelson.
Joseph F. Simpson.
Reginald Arthur Smith.
William Stead.
A. Still.
F. Thursfield.
Frederick Whiteley.

To the Class of Associate Members.—

Herbert G. Baggs.
John D. Bailie.
George Barnard.
A. B. Brook.
George Broughall.
S. H. Casson.
John Darney.
W. M. France.
Alfred E. Garbutt.
H. W. Heywood.
Samuel Jones.
T. G. Littleboy.
Alexander Marr.
E. A. Paris.
Edwin Parker.
Philip C. Pope.
W. F. Price.
Francis E. Procter.
P. A. Ramage.
George H. Scholes.
John Joseph Tinker.
Roger H. Willis.

To the Class of Associates :—

G. L. Adamson.
H. Anderson.
Albert Battersby.
Charles W. V. Biggs.
E. J. H. Christie.
S. Hartford.
E. L. Liley.
Andrew L. Lind.
David S. Mitchell.
Frank W. Page.
John B. Parkinson.
Sydney Payne.
Robert Shaw.
A. F. Stephenson.
Arnold Sugden.
Albert Wilkinson.

Mr. C. S. Thomson and Mr. H. W. Wilkinson were appointed scrutineers of the ballot for the election of new members.

A donation to the *Library* was announced as having been received since the last meeting from Mr. W. H. Lindley, and to the *Building Fund* from Mr. J. Maclean, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: I received a couple of days ago a letter from M. Mascart, the President of the Electrical Congress which is to be held in Paris in August, and to which our Institution is sending delegates. M. Mascart, as you remember, is elected as one of our Vice-Presidents for the coming year. The letter which he has addressed to me relates to contributions from possible English writers to be read at the Congress, and contains the following paragraph :—

"Pour faciliter les discussions au Congrès d'électricité, nous avons pensé qu'il serait très utile d'avoir une série de rapports sur les questions qui présentent le plus d'actualité. Quelques-uns de nos collègues nous ont promis deja des résumés sur les sujets suivants :—

1. Recapitulation des décisions des Congrès antérieurs sur les grandeurs et les unites.
2. Sur la photométrie.
3. Sur le couplage des alternateurs.
4. Sur les lampes électriques.
5. Sur les prises de courant pour tramways.
6. Sur les commutatrices et transformateurs redresseurs.
7. Sur l'emploi des condensateurs.
8. Sur les génératrices asynchrones et sur le compoundage des alternateurs.
9. Sur la galvanoplastie.
10. Fours employés a la production du carbure de calcium.
11. Télégraphie sans fil.

"Nous distribuerons dans quelques jours un programme plus détaillé pour le Congrès, comprenant, autant qu'il nous a paru, toutes les questions qui se préteraient à des communications, mais ce programme n'est pas limitatif.

"Il serait intéressant que nous puissions, en même temps que les rapports précédents, faire imprimer et distribuer aux membres du Congrès avant les séances d'autres rapports préparés par des électriciens anglais sur des sujets à leur choix. Ces rapports pourraient être très courts, de 8 à 12 pages par exemple, et nous aurions grand plaisir à les recevoir. On en ferait la traduction et l'impression en envoyant une épreuve a l'auteur.

"Vous pourriez peut-être soulever cette question devant la Société des ingenieurs électriciens et nous y recruter quelques redacteurs, dont chacun traiterait un sujet de sa compétence, et nous comptons bien que vous donneriez vous-même l'exemple."

The Council has decided, having now put before the membership this letter inviting contributions for the Congress, that all British members who propose in this way to respond to this invitation and to prepare contributions to be read at the Congress, should be invited to submit the papers beforehand to the Committee of the Council which was appointed some time ago for dealing with matters in connection with the Paris Congress.

I now call upon Mr. Eborall to read us the paper which he has prepared on "The Alternating-Current Induction Motor."

ALTERNATING-CURRENT INDUCTION MOTORS.

By A. C. EBORALL, Associate.

In the following paper some practical points connected with the construction, design, and performance of modern single and polyphase induction motors are first considered, and then follows a brief consideration of some recent developments in this branch of electrical engineering. The author originally intended to submit a short paper on starting devices for single-phase motors, but it afterwards occurred to him that it might prove of interest to bring up the whole question of alternating-current induction motors for discussion, as the subject is of considerable interest to many, and has been somewhat neglected in this country up to the present.

On the other hand, some apology is needed for presenting such a paper to the Institution, because there is little that is really new in this branch of electro-technics.

PART I.

THE CONSTRUCTION OF INDUCTION MOTORS.

(A) *Iron-work.* The design of the iron-work, that is, of the stator and rotor cores, motor case, bearings, etc., is the same for all motors, single or polyphase, because a single-phase motor is practically a polyphase motor running on one phase.[1] The general design of all induction motors

[1] While this is *perfectly true*, and although the general constructional lines *are similar in each case, it* must be borne in mind that far greater care has to

with regard to the case and bearings is fairly uniform with all makers. Up to 100 horse-power, and for pressures not exceeding 1,000 volts, most standard motors are semi-enclosed, the stator core-discs being built up inside a cast-iron case, and the bearings carried on open end shields. Thus the motors are virtually without bed-plates. Bearings are invariably provided with ring or chain oilers, and the sleeves are of gun-metal for the small sizes, and of Babbitt metal for the larger sizes. Shafts are frequently case-hardened in the neck and afterwards ground true.

For larger motors than 100 horse-power, and for voltages above 1,000, a more open construction is employed, involving the use of a bed-plate, to which the stator case and the pedestals are bolted. In this case the bearings are usually spherical. With large motors, great care has to be taken to keep the bearings absolutely rigid with regard to the stator case, on account of the relatively small air-gap. For instance, for a 300 horse-power induction motor running at 200 revolutions per minute, at 40 cycles, the diameter of the rotor works out to be about 8 feet, and the air-gap (iron to iron) would not exceed 0·2 inch. With such a motor, it is absolutely necessary to stiffen the pedestals by means of arms radiating from them and bolted to the stator case.

Stator stampings are usually not less than 20 mils in thickness, and are built up with or without insulation between them. Ventilating ducts are usually provided in the core for all sizes above 30 horse-power. Rotors are built up from stouter stampings, which need never be insulated; ventilating ducts in them need not be provided for motors less than 50 horse-power, on account of the absence of iron loss in the cores of any appreciable amount.

The windings for both stator and rotor must always be iron-clad; that is, the cores must be provided with holes or slots. In Fig. 1 are illustrated some typical forms of stator holes and slots.

The form marked *A* is the well-known Brown rectangular hole; that marked *B* is used by Messrs. Kolben

be taken with the design of a single-phase motor than with that of a polyphaser if the best results are to be obtained. The bad effects of magnetic leakage are felt far more with the former than with the latter, and the performance of the motor is affected by apparently insignificant details of design. However, a very good polyphase motor will make a fairly good single-phase motor, as a general rule.

& Co; that marked *C* is the usual shape used in Germany; those marked *D* and *E* are American forms; while finally, the slot marked *F* is generally used in the motors built by the author's firm. The greatest winding space is given with square-topped slots—the bottom of a slot or hole is best kept rounded, as it produces a more even pole.

The arguments for and against the use of holes and slots are as follows:—With the employment of a hole-winding,

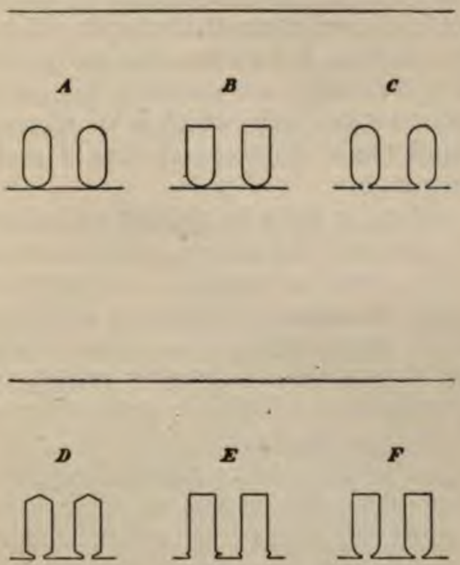


FIG. 1.

the magnetising current of the motor is reduced to a minimum, because the inner periphery of the stator is smooth all round, and consequently the area of the air-gap is as large as possible. But if the small iron bridges at the bottom of the holes are more than mere shreds of metal, of the thickness of paper, there is considerable magnetic leakage across them, which may greatly affect the performance of the motor. In order to prevent this leakage, not only have the stator core discs to be tooled after being built up, that is, a cut has to be taken off the bore of the stator, but the interior of the holes has to be filed, and so the iron losses *are unavoidably* increased. A hole-winding produces

a somewhat smoother pole than a slot-winding, but the former is much more difficult to wind, and the conductors are liable to get injured owing to abrasion of the insulation while being pulled through, especially as the holes get nearly filled up with wires, and this injury may easily escape detection at the time.

The only real objection to partly closed slots is the increase of magnetising current produced by their use (it will generally increase 10–15 per cent.), but in the author's opinion this objection is far outweighed by the smaller iron loss and greater convenience attained with slot-windings.

In many American motors the slots are quite straight, as shown, that is, their sides are parallel; this permits the use of former-wound stator coils, which is an advantage, but on the other hand, the magnetising current of such motors is relatively very high.

A hole-winding is open to another objection—unless a great many experimental data are available, it is impossible to calculate the motor in question accurately, as magnetic leakage cannot be estimated with any accuracy. On the other hand, the performance of a motor having open or partly closed slots can be accurately predetermined from the drawings, by means of suitable vector diagrams, such as those of Heyland [1] or Rothert.

With regard to the relative proportioning of stator and rotor holes or slots, the lengths of these should not, if possible, exceed 2½ times the width, and the nearer they approximate to square or circular shape, the better. This amounts to saying that the winding depth must be kept down, as otherwise the power-factor and the over-load capacity of the motor will be affected. The performance of a motor at starting, particularly if it has a permanently short-circuited rotor, and especially if single-phase, may be greatly improved by so designing the rotor that the slots or holes of the latter are not parallel to the holes or slots of the stator—for instance, they may be "staggered" by an amount not exceeding their pitch.

This constructional feature, first put forward by Mr.

[1] Refer to *Polyphase Electric Currents* (Dr. Thompson), 2nd edition, 1900; or to Mr. Heyland's latest publication, *Experimentellen Untersuchungen an Induktionsmotoren*, 1900 (published by F. Enke, Stuttgart).

C. E. L. Brown about six years ago, is used with all the induction motors built by the author's firm, including the Heyland single-phase motors, as the results of many tests show it to be of considerable value.

The insulation of holes or slots is usually effected by

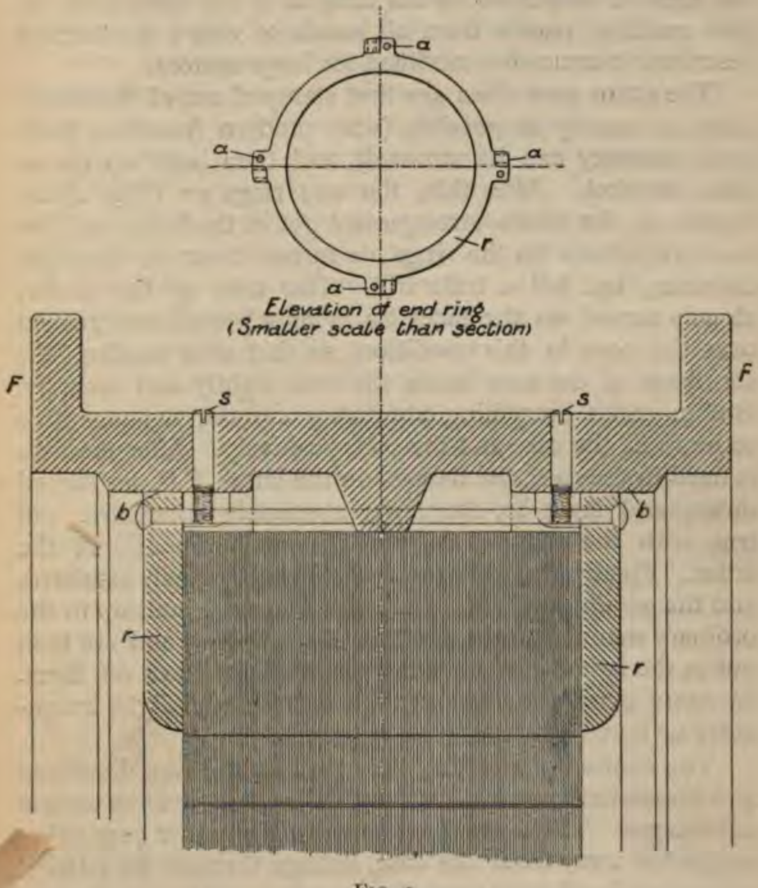


FIG. 2.

means of insulating tubes of compressed paper, fibre, veneer board, or micanite, the latter material being of course best, but not necessary for low-tension motors.

The building-up of the stator core in the motor case is an important feature of the design, and, moreover, the *details connected* with it are frequently neglected. First,

the stator core-discs should always be supported away from the case, and secondly, after having been assembled together, the stampings should not be tooled.[1] It is frequently difficult to avoid this after-tooling, more especially on account of the absolute necessity of having everything concentric, and therefore the author thinks it may be of interest to describe one method employed by his firm, as it has been found to give excellent results from all points of view; the method described is somewhat modified for large motors.

The stator core-discs are first stamped out of the sheet-metal as exactly as possible (with modern American tools great accuracy can be attained), and then built up on an iron mandrel. After this, the end rings *r r* (Fig. 2) are riveted on, the whole arrangement put in the lathe, and the four projections on the rings *a a* turned down to the right diameter, but left a trifle full. The case of the motor, already turned on the faces *b b*, is now heated, and pushed over the core in this condition, so that after cooling, the shrinkage of the case holds the core tightly and securely. But to make everything absolutely certain, two or three screws *s* fix the case and the core positively. After the core is fixed in the case, the flanges on the latter, F F, are turned down, and must be, therefore, absolutely concentric and true with the stator bore, and true with the axis of the latter. Finally, the slots and end rings are heavily insulated, and the winding put in. The rotor cores are built up in the ordinary manner on the shaft, or on a spider, and are then put in the lathe, and the finest possible cut taken off them. In some cases even this cut is omitted, any slight irregularity or burr being removed by grinding.

The method of building the core into the case described and illustrated above will readily be seen to possess several advantages. These are, first, that owing to the core being supported away from the case, leakage through the latter is minimised, and consequently wasteful eddy currents and other detrimental effects are avoided, and moreover a free circulation of air can take place all round the core; secondly, the eddy current losses in the core and teeth are reduced to a minimum, and approximate very closely to the value obtained by calculation; and thirdly, as the core-discs are

[1] See, however, previous remarks regarding hole-windings.

built up quite independently of the motor case, the width of core can be adjusted within certain limits to suit the output of the motor—a great advantage in practice, as it allows a given case to be used for motors of several sizes, and to a certain extent permits convenient variations to be made from standard designs.

It is usual with some constructors, notably with Mr. Kolben, to make the end rings or cheeks of the stator cores of brass or gun-metal. It is claimed that by doing this the leakage from pole to pole along the side flanks of the stator is sensibly diminished, or prevented altogether.

(B) *Windings.* The stator- and rotor-windings of all modern induction motors are always of the drum type, these windings consisting in all cases either of simple rectangular coils, or regular bar-windings, or modifications of the latter—for instance, the so-called squirrel-cage windings. A ring-winding has three great disadvantages; first, it has an inherently large leakage coefficient; secondly, its use necessitates the employment of a massive brass frame around the stator core (in order to minimise magnetic leakage) and it practically precludes the use of an external iron containing-case for the stator, thus making the mechanical construction of the motor difficult and expensive; and thirdly, there is much idle wire.

As already stated, the stator coils of all motors are wound either in holes or slots, and for all usual sizes of motor these coils can be wire-wound with rectangular coils. With single and two-phase motors employing wire or cable-wound rectangular coils, there will be two ranges of coils, one range consisting of simple rectangular coils with straight ends, the other range consisting of precisely similar coils, but with bent ends. Thus each phase of the motor (with single-phasers the starting coils, occupying not more than one-third of the total winding space, may be regarded as the second phase of the motor) will be made up of coils of definite shape, the coils of one phase being bent, at the ends, up and over the coils of the other phase, in order to clear them; from this arises the workshop terms of the "straight phase" and the "bent phase," as applied to two-phase and single-phase motors. With the latter type of motor, the starting phase is invariably the bent phase, from motives of convenience in winding.

With two-phase and single-phase motors, it is usual to wind all the poles; that is, considering one-phase only, the coils of this will be wound alternately right and left-handed with regard to the direction of the current in them, that is, they will be cross-connected in the usual manner.

It is clear that for three-phase stators having rectangular coils, it would be a great practical advantage if they could also be arranged for two sets of coils, as with three sets the crossings of the phases at the ends are not only a source of danger (from the insulation point of view), but prevent damaged coils from being easily repaired. Moreover, if each set is in a different plane, there is no possibility of removing the rotor without removing the "bent down" coils, unless the stator core is built up in sections—a quite inadmissible construction. Consequently, for all three-phase stators for motors of standard sizes, and for all high-tension motors, the coils of the various phases are always arranged in two sets, just as for two-phase motors, the coils of a given phase being alternately bent and straight. But in order to do this, and at the same time preserve the proper phase-relation and pitch of the coils, an important modification of the winding has to be made, namely, only poles of the same sign are wound, in each phase. For instance, considering one phase only, there will be as many coils as there are *pairs of poles*, and all coils will be precisely similar with regard to the direction of winding and to the manner of connecting them up. This winding, which simply leaves each alternate pole unwound and doubles the number of turns on the wound poles, is obviously equivalent to the winding referred to above, both electrically and mechanically, but somewhat more copper is required with it, on account of the mean length of turn being greater.

It is worthy of note that with such three-phase windings for stators having an odd number of pairs of poles, the winding becomes slightly unsymmetrical at one point, where the end connections of the phases cross one another. This can be readily seen from an inspection of Fig 3, which shows a six-pole stator. Although for high-tension motors, and for very large low-tension motors, this may be an inconvenience, it is not found to present disadvantages in practice, for motors of standard sizes and voltages. As a

general rule too, the speeds of high-tension motors can be so chosen that the number of pairs of poles required is even, while for the large low-tension motors, having an uneven number of pole pairs with bar-windings, it is perfectly safe and allowable to wind the stator with three ranges of coils, the end connectors being bent up and back as shown in

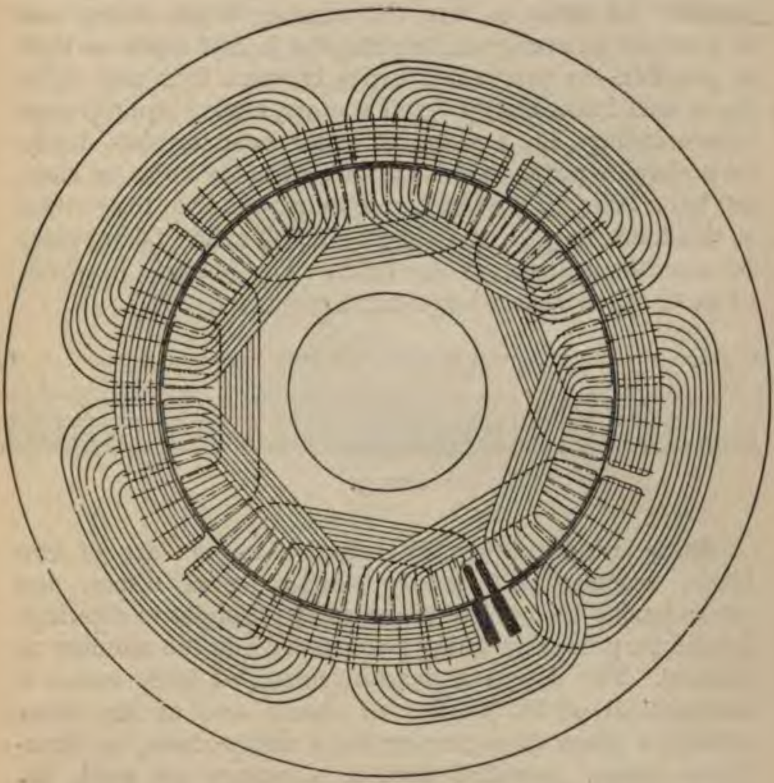


FIG. 3.

Fig. 4. Or, should this mode of construction be deemed inadvisable, on account of space for the end connections being limited, or for other reasons, the stator for such large motors can be conveniently and effectively wound with a closed bar-winding. Such a bar-winding, drawn out schematically for a two-phase motor, is shown in Fig. 5, the four-pole case being taken for simplicity.

Standard *three-phase* stators wound with rectangular coils

invariably have the coils connected star fashion. Stator l windings for large low-tension motors can be, and ve frequently are, used with the mesh connection. Combinations of star and mesh are rarely or never found with modern three-phase motors.

The number of holes or slots per stator pole per p has an important bearing upon the design of all induc motors. In order to keep the winding depth down, an to produce an even pole, this number is best made as high as possible—in practice it varies between four and eight. As is well known, with small motors, having squirrel-cage rotor-windings, the number of stator holes or slots should be preferably prime to the number of rotor holes or slots, the latter being, if possible, more numerous than the former, as this tends to prevent a cogging acting action taking place between the stator and rotor fields. The point is, however, of small importance when wound rotors are used.

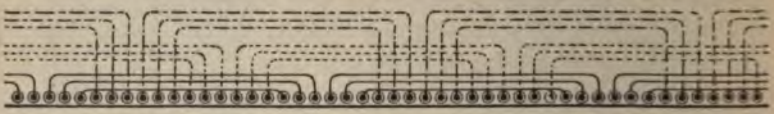


FIG. 4.

Rotor windings for all induction motors are of two kinds, namely, permanently short-circuited rotors, and rotors having the ends of the windings brought to slip-rings for the purpose of inserting a resistance into the winding at starting. The design and arrangement of these rotors is independent of the number of phases and of the stator voltage, a given rotor serving for a single-, two-, or three-phase motor, provided that, if slip-rings are used, the number of stator poles is the same in each case, and that the flux per pole in the gap has the same value. There appears to be some difference of opinion as to how far the permanently short-circuited rotor can be used with satisfactory results—that is, at what output of motor it is best to bring in the starting resistance. For motors *having to start against load* (apart from crane, elevator, and mining motors), the author is decidedly of opinion that the squirrel-cage construction, or its modifications, should be avoided with all polyphase motors above 5 B.H.P. With single-

motors, which are usually arranged to start up light, d rotors with slip-rings should be used over $7\frac{1}{2}$ B.H.P. the Heyland single-phase motors, referred to at length on, a starting resistance in the rotor is used for all . If the use of the permanently short-circuited rotor ished too far, the pressure regulation of the system,

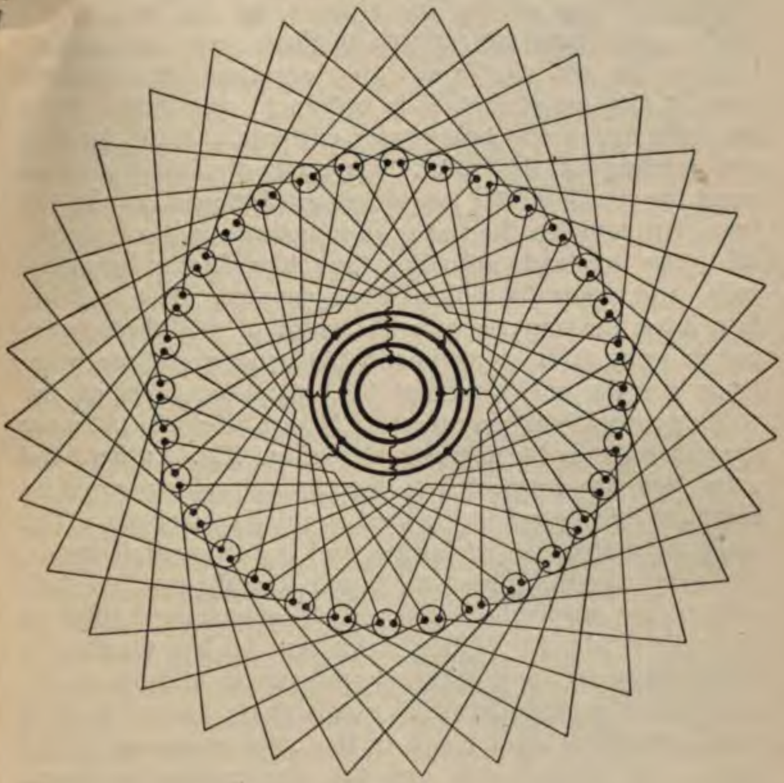


Fig. 5.

whatever the number of phases, is greatly impaired, owing to the excessive current consumption during the starting up of the motors. When it is considered that the best polyphase motors with squirrel-cage rotors, and starting under full load, require a momentary rush of current equal to at least two and a half times the full-load current, this statement will be readily believed. It must not be forgotten in this *connection*, that under such circumstances,

the power factor at the moment of starting will be low, with the result that the drop on the transformers, and perhaps even on the generators, is still further increased.

With regard to squirrel-cage rotors, and to the modification of them, the rotor wire-wound with closed coils, there is not much to say. The chief difficulty with the former lies in the fact that it is difficult to make a good mechanical job of the connections to the end rings. If the rotor bars are screwed to these rings, the contact between bar and ring is not only uncertain, but however good it may be at first, it is certain to deteriorate under the influence of the heavy rotor currents, and the heating and cooling of the rotor. Consequently, most makers sweat the rings over the projecting and flattened ends of the bars. But with this, the rings will sometimes melt completely off under overloads, splashing the solder all over the stator coils, and generally doing other damage. The author's firm braze the rings on, when a motor of this character is put to work of an exceptionally heavy nature, where overloads are the rule and not the exception, or when the starting conditions are severe. Messrs. Kolben get over the difficulty in the manner shown in Fig. 6; here the rotor bars are connected to the short-circuiting rings by means of thin copper strips, used as radial connectors. The rings themselves are of bronze, and are of small diameter, but very massive; they are keyed directly on the shaft without any insulation whatever. In a communication to the author, Mr. E. Kolben states that he has found this construction to prevent entirely the evil mentioned above, and that it greatly assists his single-phase motors to start well,—doubtless on account of the extra resistance in the strips. Mr. Kolben also uses this construction for larger motors for crane and similar work (where large starting torques are required without, if possible, the employment of a starting resistance) as it allows of the insertion of the resistance strips of brass or other material, in place of the copper connectors.

Several firms, notably the Oerlikon Company, avoid the squirrel-cage construction altogether, by winding the rotor with closed coils. In this case the rotor winding may either consist of a regular wave winding, taken all the way [illegible]d either once or else several times and finally short-

circuited, or better, of a number of coils, or groups of coils, separately short-circuited. Such wire-wound rotors are naturally more expensive than either of the forms described above, and are frequently difficult to wind, on account of the trouble experienced in handling the heavy conductors.

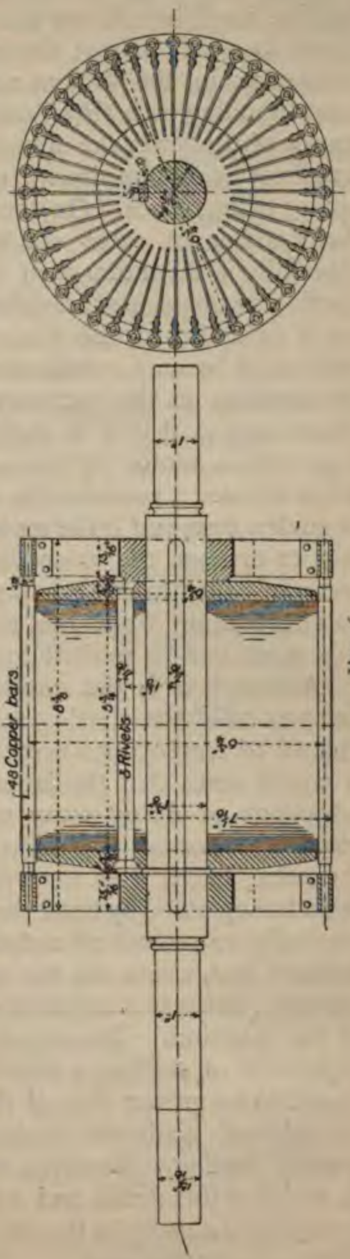


FIG. 6.

The employment of wound rotors and non-inductive starting resistances is, as already indicated, always preferable for motors of any size. Here the rotors are invariably wound with a three-phase star-connected drum-winding, which may be carried out either with overlapping (rectangular) coils, or with two or four bars per hole or slot, arranged as a cylinder wave-winding.

The common junction to the three phases of such a winding is frequently the iron-work of the rotor; this is very convenient with motors of considerable size, where the conductors are usually massive. Star-connected bar-windings of this character are always unsymmetrical, and "false connections" have to be made in each phase.

A point to be remembered when designing wound rotors for high-tension *motors is the* fact

that the rotor volts per phase (that is, the voltage between any two slip-rings at normal stator pressure when the brushes are lifted off and the motor is at rest) must be kept down to a safe value : this is because at starting, with all resistances in, the voltage across each resistance (and the corresponding two rings) may be sufficiently large to be a source of danger to the attendant, if the turns in the winding have not been kept down ; moreover, there is some risk of arcing taking place. On the other hand, in no case must the number of rotor conductors in series be too few, especially if the motor is of large size, else the cost of the starting box becomes excessive, and, if this latter is mounted on a switchboard, the three heavy cables coming to the latter may become inconvenient to arrange for ; moreover, the contacts on the box may give trouble. It may sometimes happen that it is desirable to regulate the speed of a polyphase motor (by means of the rotor resistance) at a point situated a considerable distance away from the motor; in such a case, and if the motor is for a low voltage, it may pay to arrange the rotor-windings to transform up, as it were, in order to effect a saving on the cost of the three cables, coming from the rings to the starting box, but this must not be pushed too far.

Although it is the standard practice with one or two firms to build the starting resistance within the rotor itself, instead of employing a separate starting box and slip-rings, it would seem that the latter practice is the better. The advantage of doing away with the external arrangement consists, of course, in getting rid of the sliding contacts ; on the other hand, it is easy for the short-circuiting device (whether operated by hand through the hollow shaft or automatically) to get out of order, inspection of the contacts is difficult, and, above all, the motor is brought up to speed abruptly, because a subdivided resistance is practically out of the question. Consequently, the effect on the pressure regulation of starting a motor so fitted under heavy load is bound to be greater than if the motor had been fitted with an external graduated resistance, permitting of easy and gradual starting. However, several firms are now engaged in studying this detail, and considerable improvements may be expected shortly in the electrical and mechanical design of internal starting gear.

(C) *Notes on Performance and Design.*—An analysis of the guaranteed performance of a given type of open or semi-enclosed induction motors between 2 and 100 B.H.P. built by any of the best Continental or American makers, and whose construction is on the lines indicated above, may be set forth as follows :—

1. No-load Current. Expressed as a percentage of the full-load current, the values for this will be as under :—

			Poly-phasers.		Single-phasers.
For motors between	2–5 B.H.P.	inclusive	30%	...	40%
Do.	$7\frac{1}{2}$–20	do.	25%	...	30%
Do.	25–100	do.	20%	...	25%

2. Overload Capacity. This is sensibly the same for all sizes with a given line of motors run at constant stator pressure, and will be as follows :—

	Polyphasers.	Singlephasers.
For one hour[1]	50%	Varies considerably,
Before falling out of step	90%	but generally small.

3. Full-load Drop of Speed (Slip). At constant pressure on the stator terminals this will be :—

For induction motors between	2–5 B.H.P.	inclusive	7%
Do.	$7\frac{1}{2}$–15	do.	5%
Do.	20–40	do.	4%
Do.	50–100	do.	3%

4. Heating. The final temperature-rise after a long continuous run at full load will not exceed 40° C. for semi-enclosed motors having outputs between 2 and 25 B.H.P., and 30° C. for larger sizes.

5. Full-load Efficiency. For semi-enclosed motors with hot windings the values for five representative sizes will be as follows :—

	2	5	10	25	50 B.H.P.
Polyphase motors ...	75%	79%	85%	87%	90%
Singlephase motors ...	73%	77%	83%	86%	89%

[1] The temperature rise not exceeding 70° C. for semi enclosed motors, and less for *open-type motors*.

6. Full-load Power-factor. The values for this quantity for five such representative motors will be :—

	2	5	10	25	50 B.H.P.
Polyphase motors ...	78%	80%	85%	87%	88%
Singlephase motors ...	72%	75%	80%	83%	85%

7. Weight per B.H.P. The nett weight per B.H.P. (that is, not including the weight of the rails, pulley, and starting resistance, if any) of the five representative motors designed and constructed on the above lines will not come out much below the following values :—

	2	5	10	25	50 B.H.P.
Polyphase motors ...	80	58	56	40	40 lbs.
Singlephase motors ...	115	88	66	62	62 „

NOTE.—The values given in Nos. 1 to 7 above are for 50 cycle motors at voltages of 110, 220, 440, or 500 volts, having the following number of stator poles per phase :—

All motors between	2–7½ B.H.P.	inclusive,	four poles.
Do.	10–30	do.	six „
Do.	40–100	do.	eight „

The various values, however, for 40 and 60 cycle motors having the same number of poles are practically the same as those given above.

A standard line of induction motors constructed on the lines already indicated, and to which the above figures relating to performance apply, would have the following general technical data.

1. Peripheral Speeds :—4,000 to 7,000 feet per minute, according to the size of the motor.

2. Ampere-conductors per inch of stator (inner) periphery at full load.

B.H.P.	Ampere-conductors per inch.
2 to 7·5	250
10 to 30	330
40 to 100	430
100 to 150	570
Above 200	600

3. Flux Densities per square inch. In the stator teeth :—

B.H.P.	Maximum value of B.
2 to 7·5	65,000
10 to 30	70,000
40 to 100	80,000
Above 100	85,000

In the rotor teeth :—

B.H.P.	Maximum value of B.
2 to 7·5	80,000
10 to 30	85,000
40 to 100	90,000
Above 100	100,000

In the air-gap the flux-density should never exceed 30,000 lines per square inch. The flux-density in the stator core is determined solely by the permissible loss, and does not otherwise affect the performance of the motor.

The above figures give very good results for 50 $\sim$ motors having partly closed slots for both rotor and stator. With motors for higher frequency, and for hole-wound stators and rotors, smaller values must be taken.

4. Current Densities per square inch. With low and medium pressure semi-enclosed motors, the amperes per square inch in the stator windings at full load will be between 1,500 and 1,100, according to size, while in the rotor bars the current density will be about 15 per cent. higher. With high-pressure motors, somewhat smaller values must be taken in the stator on account of the relatively larger space taken up by insulation.

5. Length of Air-gap. This is always to be made as small as possible, and is determined wholly by mechanical considerations. Usual values for the length of air-gap, that is, the distance from iron to iron, are :—

Rotor Diameter.	Air-gap Length.
Up to 4 inches inclusive ...	1/100 inch
Between 5 and 8 inches inclusive	1/75 "
" 9 and 12 " ...	1/50 "
" 15 and 20 " ...	1/32 "
" 24 and 32 " ...	1/16 "
" 40 and 60 " ...	1/8 "

Although the above figures relating to the design of induction motors have been taken wholly from practice, it is perhaps necessary to point out that it is not possible to apply hard and fast rules and constants when designing such motors—experience in designing and a large quantity of experimental data for the type in question are absolutely necessary if the best results are to be obtained.

PART II.

STARTING DEVICES FOR SINGLE-PHASE INDUCTION MOTORS AND SOME NOTES ON RECENT DEVELOPMENTS.

It is not too much to say that more attention has been given to the question of starting devices for single-phase induction motors than to any other problem connected with single-phase working. The first difficulty was to get such motors to start at all; then after this was overcome, there came the question of reducing the heavy starting current; finally it was sought to so improve the starting device as to permit of the motor starting against load, still with a moderate current consumption. In the six years during which the subject has been before electrical engineers, successive improvements have taken place, and it is to the latest development in single-phase motors that the author wishes more particularly to refer in this part of his paper, namely, the new motor of Mr. Alex. Heyland. Before doing so, however, it may perhaps not be out of place to consider very briefly the underlying principles of all single-phase induction motors, although, of course, there is nothing new to be said on the subject in these days.

It has already been stated that a single-phase induction motor is nothing more than a polyphase motor running on one phase. Let, for instance, a two-pole two-phase motor be running from two-phase mains without load. Neglecting (as may quite well be done) the trifling power current required to make up the motor losses (under these circumstances practically only iron, ventilation, and friction), the current read on an amperemeter in each phase is the "magnetising current" of that phase of the motor—that is, it is the wattless current required for driving the magnetic flux through the magnetic circuits of the motor; further,

the speed is synchronous. Now let one phase be switched out. The motor will go on running as a single-phaser at practically the same speed, but the amperemeter in the remaining phase will read approximately twice the current that it did before—that is, the magnetising current in this phase has doubled. What has happened is briefly as follows:—The magnetic flux originally provided by the switched-out phase is now replaced by a flux of approximately the same value and relative position furnished by a magnetising current in the rotor. Magnetising currents are called into being in the rotor, induced by the magnetic flux of the phase still connected to the mains, and in quadrature with this flux with regard to time, and these currents are carried round nearly 90° in space by the practically synchronous rotation before reaching their maximum. Thus the cross-flux produced by them has very nearly the same effect as that formerly produced by the switched-out phase. The magnetising current in the rotor has, of course, to be balanced by a corresponding stator current, so that the amperemeter reads the magnetising amperes of phase 1, plus the magnetising amperes of the rotor transferred to the winding of phase 1. Hence the magnetising current in the latter approximately doubles.

With this perfect motor running at synchronous speed, it would be found that a voltmeter connected to the terminals of the switched-out phase would give a reading equal to the pressure on the mains from which phase 1 is running. This E.M.F. is that induced by the cross-magnetisation of the rotor magnetising currents, and is in quadrature with the impressed E.M.F. of phase 1, as already stated. In commercial motors the E.M.F. of phase 2, measured in this way, is not quite equal to that of phase 1. The magnitude of the difference between the two voltages is a measure of the quality of the design of the motor.

It has been said above that the motor continued to run as a single-phaser at practically the same speed. In reality the speed is a trifle less (the difference being too small to detect on a counter), owing to the fact that the rotor currents cause a slight slip, so that even a single-phase motor without friction and ventilation losses (unlike the polyphase motor) cannot run at a synchronous speed at no load.

Of course, as the rotor is loaded, the rotor power currents called into being by the load are magnetically balanced by corresponding stator currents (when the rotor and stator coils are co-axial, or approximately so) and the slip increases, that is, the speed departs more and more from synchronism. Owing to this latter circumstance the induced rotor magnetising currents are carried round in space less than 90°; the cross-magnetisation produced by them is accordingly shifted from the most effective position, until with continually increasing load there comes a point at which the torque due to the cross field and the rotor load currents attains a maximum value—if this value is exceeded the motor pulls up. When the rotor is stationary, the cross-magnetisation is reduced to zero; there remains now only the one flux of the phase connected to the mains (phase 1), and this flux cannot possibly produce a torque—that is, the motor cannot start—because its axis (that is, the axis of the exciting coils of phase 1) coincides with the axis of the current carrying coils of the rotor.

In order, therefore, to enable a single-phase induction motor to start at all, an auxiliary starting field must be created that will do exactly the same thing as the rotor magnetising currents do at synchronous speed. That is, with regard to space, a magnetic flux must be established in quadrature with the principal flux inducing the rotor currents; and with regard to time, this auxiliary flux must coincide with the rotor load current—that is to say, it must be approximately 180° behind the corresponding stator current. Every single-phase induction motor must therefore be provided with a device to produce a suitable cross-flux in the air-gap, and the amount of starting torque available will depend purely upon the value of this cross-flux, and upon the effectiveness of its time relations as stated above.

All single-phase induction motors are provided with starting coils wound in the useless winding space of the stator. They rarely occupy more than one-third of the total stator winding space, and frequently less; moreover, these coils are invariably so arranged that the magnetic axis of each coil is in quadrature[1] to the magnetic axis of the

[1] A notable exception to this disposition is the arrangement that has been used for many years by the Swedish firm of Wenström for their small single-phase motors, which have the starting coils "staggered" from the position indicated here.

corresponding running coil—a disposition exactly fulfilling the "space" requirement stated above. The difference existing between the various starting devices lies mainly in the various methods of producing the requisite phase relation of the cross-magnetisation.

With the exception of the Heyland motor, all the devices employed for producing this requisite phase difference are external to the motor, and they have all been devised at one time or another by Mr. C. E. L. Brown, and have gradually been adopted by all other single-phase motor builders. These external starting devices take the special form of arranging that the self-induction of the circuit including the starting coils has a much higher value than that of the circuit containing the running coils, this being attained by suitable winding proportions in conjunction with choking coils or non-inductive resistances, or condensers; or any two of these in one or other of the stator circuits. The choice of such apparatus is governed by the relative value of the turns in the starting and running coils, and by the particular connections used at starting.

The starting torque given by motors arranged in this way is inconsiderable, barely sufficient in fact to run the motor up to speed against the load of belt and loose pulley. Moreover, unless the motor is very carefully designed—particularly from the magnetic leakage point of view—the starting current at this small torque will be excessive. With the above-named exception, the very best single-phase induction motors of the present day working under the most favourable conditions require a current at starting at least equal to the full-load current in order to run them up to speed without the load, while against the full load they will not start at all, whatever the value of the starting current.

The principal reasons for these comparatively indifferent results are, that the phase difference at starting produced by the above-mentioned means is small, and that the cross-flux produced by the starting coils does not attain a high value. As with independent alternating-current circuits a large phase difference will be produced by increasing the self-induction of the circuit, it might be thought that this could also be obtained in a motor by arranging the starting device and starting coils on these lines. But it must be remembered that the *stator circuits of* an induction motor are not really

independent, on account of the action of the rotor currents. These behave with regard to the stator currents just as the loaded secondary of a transformer behaves with regard to the primary—that is to say, the self-induction of the stator windings is more or less completely wiped out by the mutual induction of rotor and stator. It follows from this that better results will be obtained if the number of turns of the starting coils is kept low, and the increase of self-induction produced by an external choking coil, or equivalent device involving magnetic leakage. This point was recognised at an early stage by motor builders, and an external choking coil (to produce as much phase difference as possible) is a leading feature of several modern starting devices.

But this increase of self-induction, whether produced externally in this way, or by winding the starting coils with a large number of turns, effectually prevents the starting field of the motor (that is, the field in quadrature position to that of the stator running coils) from attaining that high value already shown to be absolutely necessary if a large starting torque is required. Where the self-induction is increased by increasing the turns of the starting coils, the strength of the cross-flux falls off inversely as the square root of the self-induction; if the choking coil is used, the strength of the cross-flux is diminished by an amount equivalent to the leakage flux of the coil. Consequently, it is evidently a clear fundamental point, that to obtain a large starting torque the self-induction of the starting coils should be kept down as much as possible.

It has been hitherto generally held that the design of starting devices for single-phase induction motors should be such that the starting conditions should approximate as nearly as possible to the starting conditions of polyphase motors—that is, designers have aimed at the production of a rotary field at starting. Not only this, but every effort has been made to make this field as uniform as possible, by so proportioning the windings of starting and running coils as to produce two equal magnetic fluxes, and the production of a larger field by one or the other winding has been particularly avoided.

Mr. Heyland's motor, which is shown here to-night, and described below, is designed with regard to the starting device on exactly opposite lines to these. Briefly, there is

no external phase-shifting device, the starting winding being put straight on the mains, and this winding has comparatively few turns, and is so arranged that under all circumstances its self-induction is less than that of the running coils—that is, the winding carrying the current of greater phase difference is made to have the smaller self-induction. As a result of the small self-induction of the starting coils, a cross-magnetic flux of great strength is

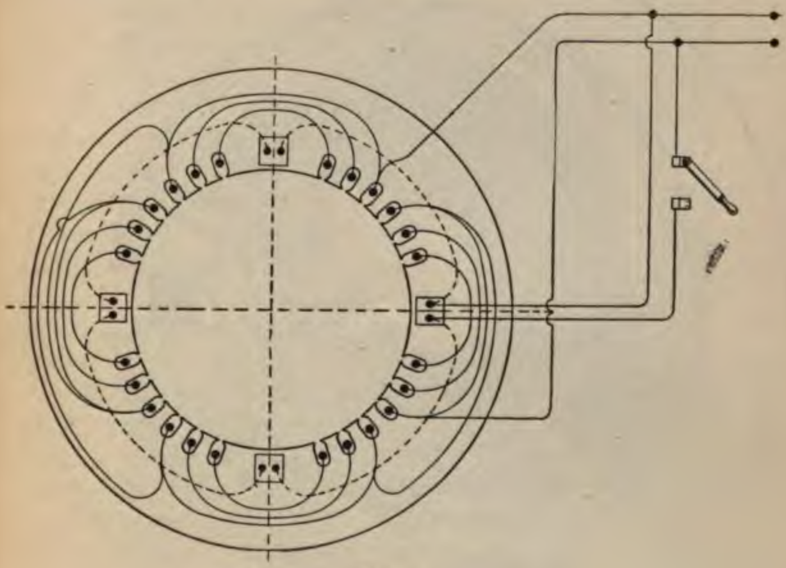


FIG. 7.

available, and this cross-flux is made to have the proper time relation by a special arrangement of the magnetic circuit of the stator. The production of a rotary field at starting is not aimed at, the whole idea of the starting device being to produce a powerful alternating magnetisation having the proper phase relation, in a direction (considering the two-pole case) at right angles to the axis of the running coils. The result is, that the Heyland single-phase motors will all start against full load, quite easily, without an excessive current consumption, and it will be therefore readily admitted that an important advance has been made in single-phase motor work.

Apart from the design and arrangement of the starting device, the Heyland motors differ but little from other well-designed motors of the induction type. The stator running winding consists of a number of rectangular coils wound in half-closed slots in such a manner that magnetic

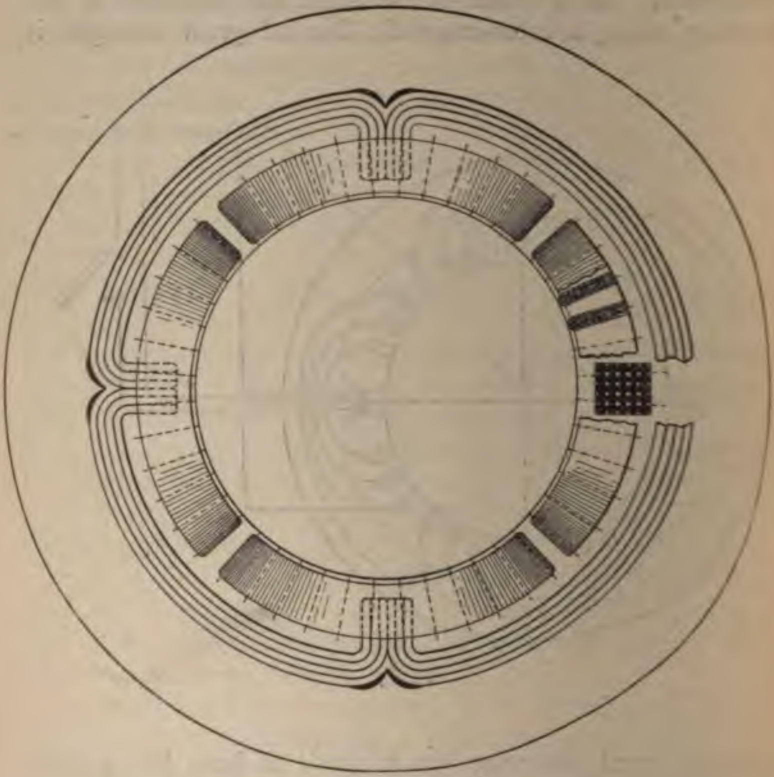


FIG. 8.

leakage is as small as possible, while the rotor is wound with a regular three-phase star-connected winding, with its three free ends connected to slip-rings on the shaft, for the insertion of a starting resistance. A squirrel-cage rotor, or one of its modifications, could be easily used, but it has been found that the reduction of the starting current (for a given torque) brought about by the use of the resistance well repays its use, even for motors as small as one horse-power.

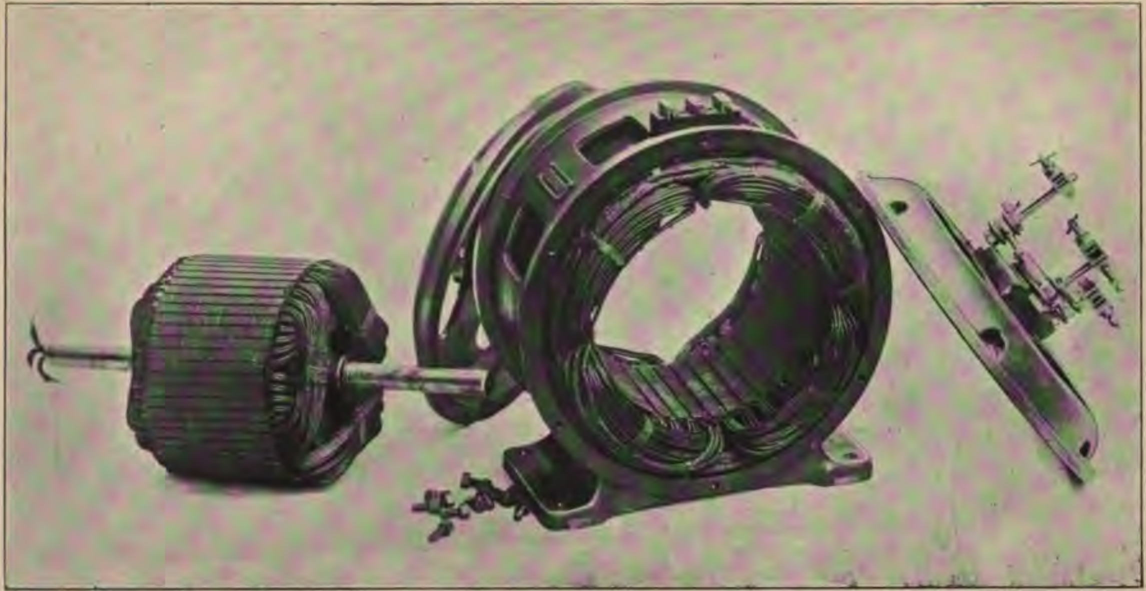


FIG. 9.

Fig. 7 illustrates diagrammatically the stator windings of the Heyland single-phase motors, the figure illustrating a

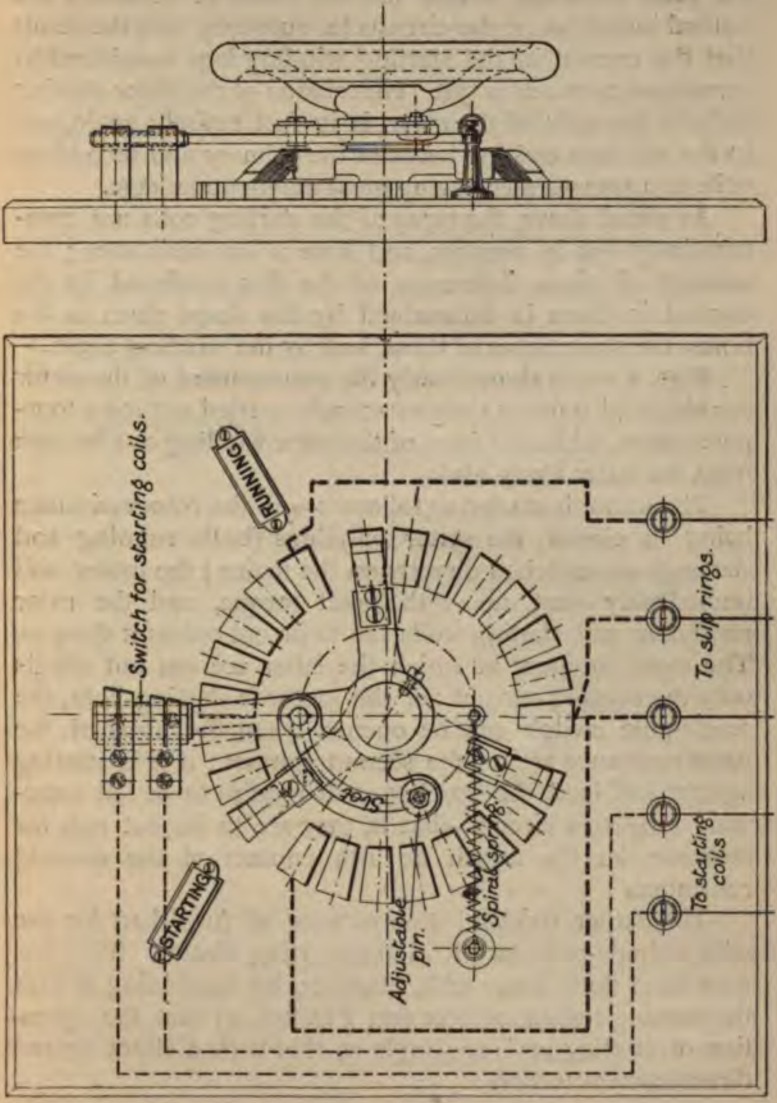


FIG. 10.

four-pole motor. The running coils are shown by the full lines, and the starting coils by the dotted lines. These latter coils are wound in rectangular holes in order to obtain the

necessary large phase difference of the current in them; the flux produced by these coils links very unfavourably with the rotor windings, which has the effect of reducing the mutual induction of the circuits in question, with the result that the current in the starting winding lags considerably, sometimes as much as 50°. The relation of the stator starting coils to the coils of the rotor, is in fact entirely analogous to the relations existing between the primary and secondary coils of a transformer having great magnetic leakage.

As stated above, the turns of the starting coils are comparatively few in number, and have a low resistance; the amount of phase difference of the flux produced by the current in them is determined by the shape given to the holes, the dimensions of these, and by the winding depth.

Figs. 8 and 9 show clearly the arrangement of the stator running and starting coils as actually carried out for a four-pole motor, while the form of the rotor winding can be seen from the latter figure also.

The motor is started as follows:—All the rotor resistance being in circuit, the stator windings (both running and starting) are switched directly on the mains; the motor will immediately start up with great torque, and the rotor resistance and starting coils are to be cut out as it does so. The exact moment at which the latter are cut out affects only the starting current: if the motor is starting light, the single-pole switch can be opened when the arms of the rotor resistance are on the second contact; if it is starting against full load, the starting coils require to be left somewhat longer in circuit—that is, they are to be cut out, for instance, on the fourth or fifth contact of the starting resistance.

The earlier Heyland motors were all furnished for use with a single-pole switch in the starting circuit. This has now been done away with, however, by combining it with the starting resistance box (see Fig. 10), so that the operation of starting up is as simple as that with a shunt wound direct-current motor.

Performance.—The Heyland motors standardised for circuits of 40, 50, and 60 cycles are designed in three ways, as follows:—

(*a*) To start without load. Under these circumstances

the starting current does not exceed four-fifths of the full-load running current.

(*b*) To start with two-thirds of the full-load torque. Under these circumstances the starting current does not exceed $1\frac{1}{2}$ times the full-load running current.

(*c*) To start with full-load torque. Under these circumstances the starting current does not exceed twice the full-load running current.

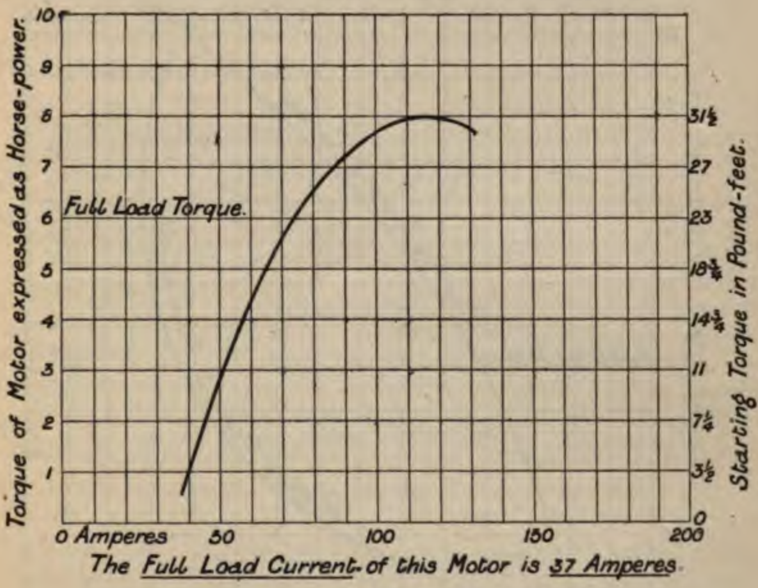


FIG. 11.

Design (*a*) has been evolved in order to conform to the ideas of many station engineers in this country. Design (*c*) represents the normal winding; while design (*b*) is frequently asked for. The starting torque with the standard stampings is determined purely by the number of turns of the starting coils and the permissible current; this torque can be arranged to have a value equal to two or three times the full-load running torque, if enough current is given to the starting coils, the limiting value occurring at the saturation point of the iron.

Figs. 11 and 12 illustrate the starting performance of two

motors designed to fulfil conditions (*b*) and (*c*) respectively, while Fig. 13 illustrates the running performance of the motor whose starting curve is given by Fig. 11. All these curves represent the results of actual brake tests, and many motors built have given better results than indicated here.

Particular attention is given in all the designs to the overload capacity of the motor, and all motors are

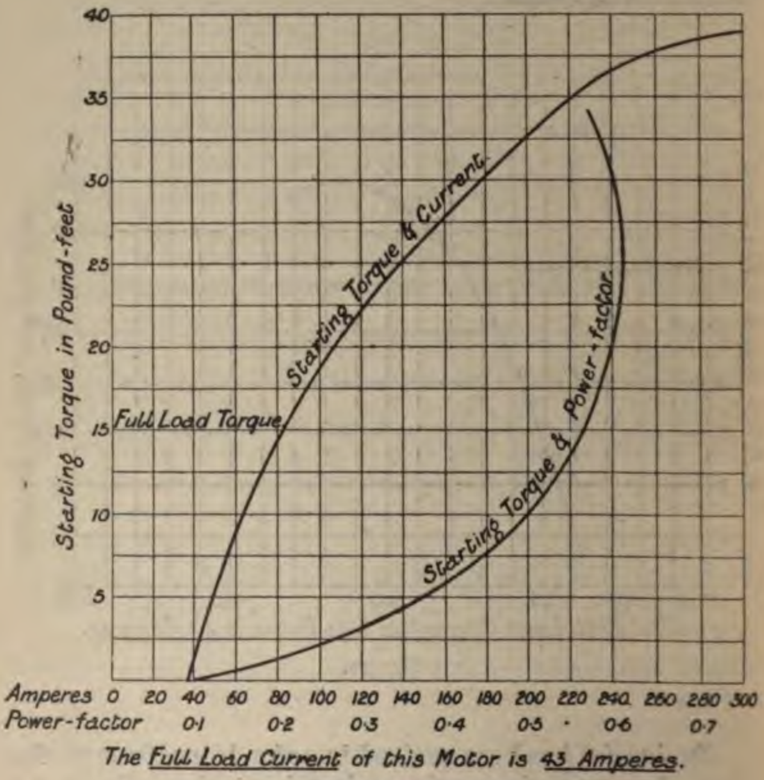


FIG. 12.

guaranteed to stand a 25 per cent. overload for one hour. The small overload capacity (varying from 0 to 10 per cent.) found with the alternating-current motors hitherto used[1] has been one of their worst features, as for most work it is impossible to fix the amount of power required so exactly

[1] The author would here like to make an exception in favour of the Wenström motor, whose overload capacity (as found with examples tested by him) is everything that can be desired.

as this, with the result that the motors installed are invariably too large and costly for the work they have to do. This reacts on consumer and supply company alike: the former has to pay for a larger motor than he wants, which will be working on the average at low efficiency, while the latter most of the time is supplying an underloaded motor, having a low power-factor.

The results obtained with the Heyland motors for circuits of 80 and 100 cycles are not quite so good as those given above, with regard to starting torque. That is to say, these high-frequency motors as built up to the

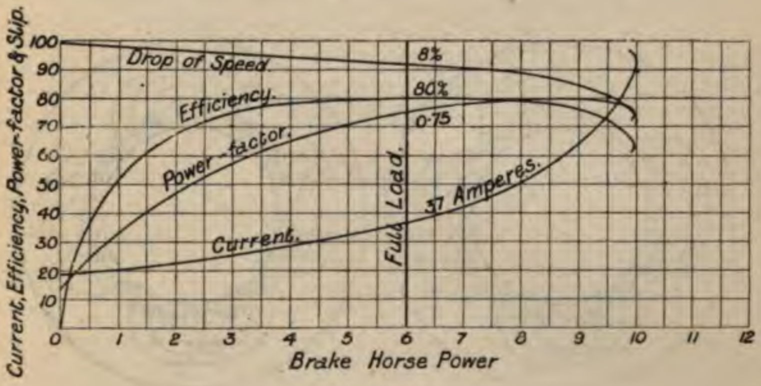


FIG. 13.

present take a relatively greater current for a given value of starting torque, the values being—(*a*) when starting without load, current is equal to the full-load current; (*b*) starting with half the full-load torque, the current is $1\frac{1}{2}$ times the full-load current; (*c*) starting with full-load torque, the current consumption is $2\frac{1}{2}$ to 3 times the full-load current. The increased values of current consumption are of course due to the larger number of poles necessary to bring the speed to a reasonable figure; particularly in small motors the number of poles has a very great effect on the amount of magnetic leakage with a given design.

As, however, the Heyland motors are not yet fully standardised for 80 and 100 cycles, the designers hope to effect considerable improvements within the next few

months in the direction of reducing the current for a given value of starting torque.

Before leaving the subject of these motors, the author would like to draw attention to an exceedingly neat method Mr. Heyland has devised for regulating the speed of induction motors, single and polyphase.

As is well known, there are two principal ways of altering the speed of such motors, the supply frequency being constant.[1] The first is by rheostatic control, a non-inductive regulating resistance being in circuit with the rotor windings, while the stator windings are connected directly to the mains; the second is by altering the number

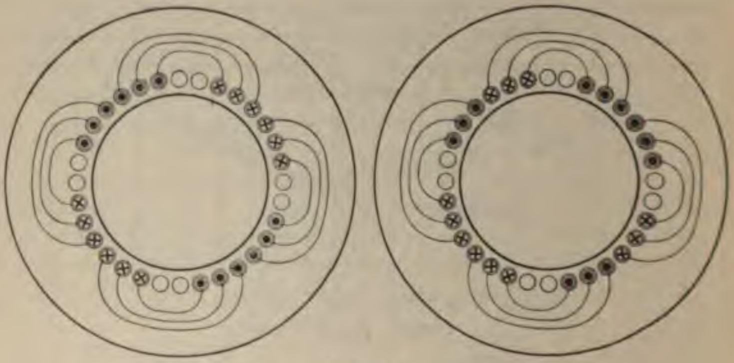


FIG. 14.

of stator poles by means of a suitable controller, together with those of the rotor, unless the latter is of the "squirrel-cage" type. Here the motor is wound for the maximum number of poles, and when it becomes necessary to pass from a greater to a less pole number, in order to get increased speed, the windings on some of the poles are reversed, thus producing fewer poles, which are in consequence much broader. For instance, in order to double the speed, half the poles have their windings reversed, the stator having now half the number of poles, each of double the former breadth. While rheostatic control is simple and

[1] The method of "tandem parallel control" for two motors while excellent theoretically, is hardly likely to come into commercial use at present, on account of the great complication involved, and because of the bad conditions under which the motors have to work.

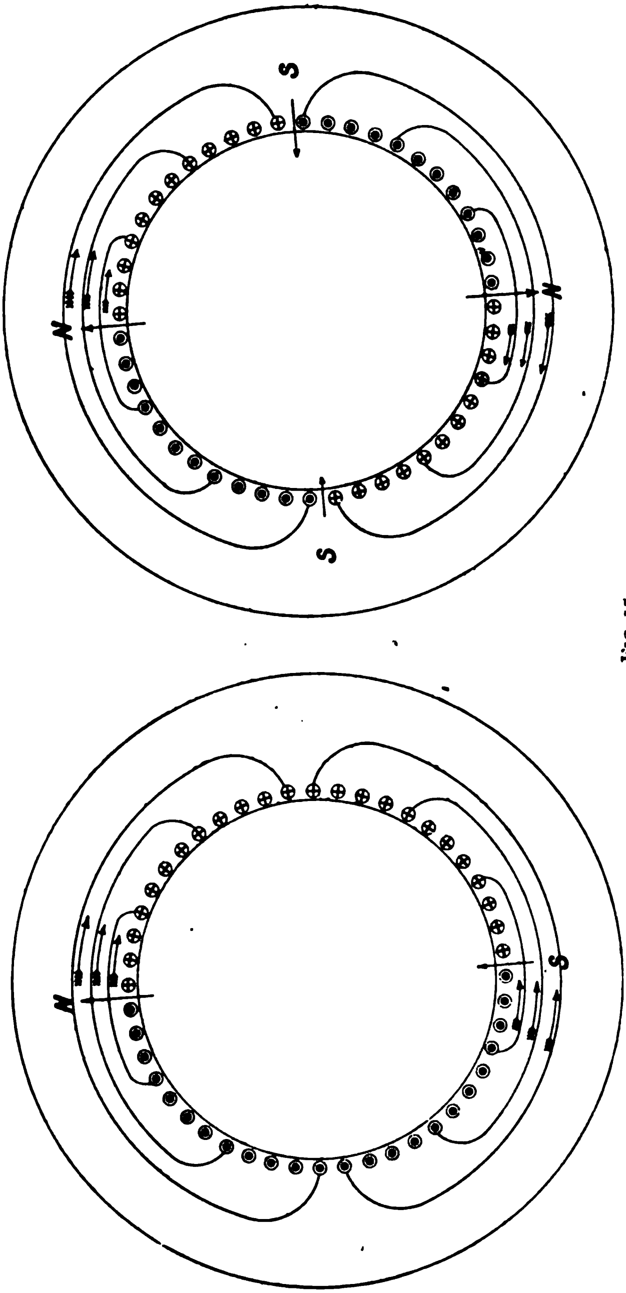


FIG 15.

easy to use, it has the great objection of being very uneconomical. The waste of energy brought about by its use is entirely analogous to that found with shunt wound direct-current motors, with constant field excitation and a regulating resistance in the armature. The case of the induction motor is really more unfavourable, because it has been found by experience that the motor has to be rated very liberally, in order to get the necessary power.

On the other hand, the method of altering the number of motor poles has two serious disadvantages. Firstly, the reduction of the number of poles causes an unfavourable distribution of the magnetic flux, a large increase of magnetic leakage and a loss of winding space. This is of course owing to the fact that after the reversal of the appropriate coils the currents flowing down one side of these coils are neutralised by the currents in the adjacent side of the unreversed coils, as will be readily seen from Fig. 14 illustrating the single-phase case.

Secondly, unless the motor has a squirrel-cage rotor, the rotor circuits become very complicated; the polarity of the rotor windings has to be changed each time in accordance with the stator polarity, which means that a large number of slip-rings have to be used, in order that this may be done.

Mr. Heyland's method consists of certain winding arrangements which, when it is desired to change the number of poles, render any reversal of the rotor windings superfluous, and to a large extent obviate the drawbacks stated above in the reversal of the stator coils.

The method of winding the stator as applied to single-phase motors is illustrated in Figs. 15, 16, 17 and 18, the last figure showing how the stator coils are wound in practice. In all cases the winding is carried out for the *smaller* number of poles, and *divided into sections*, one or more of these sections being reversed to obtain a greater number of poles. Thus, for instance, in Fig. 15 the stator being wound initially for two poles, by reversing one of the sections of the winding a four-pole stator results, as indicated, and it will be seen at a glance that there is no neutralising action between adjacent conductors, and that the distribution of magnetic flux in the air-gap will be perfectly good. Fig. 16 shows the arrangement for a four-

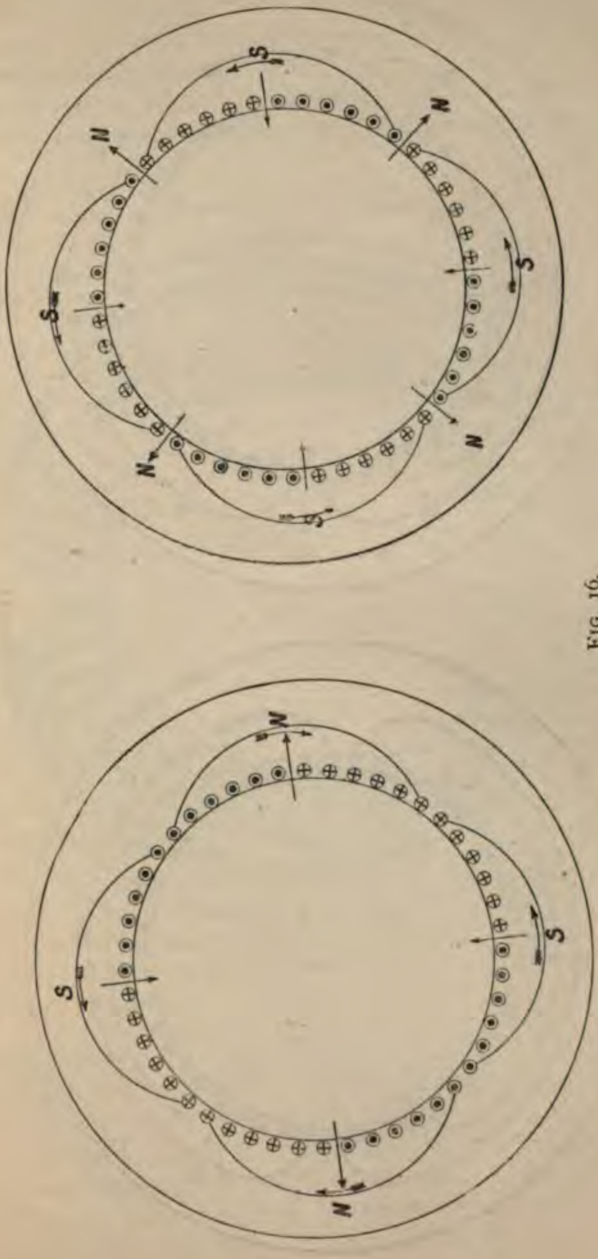


FIG. 16.

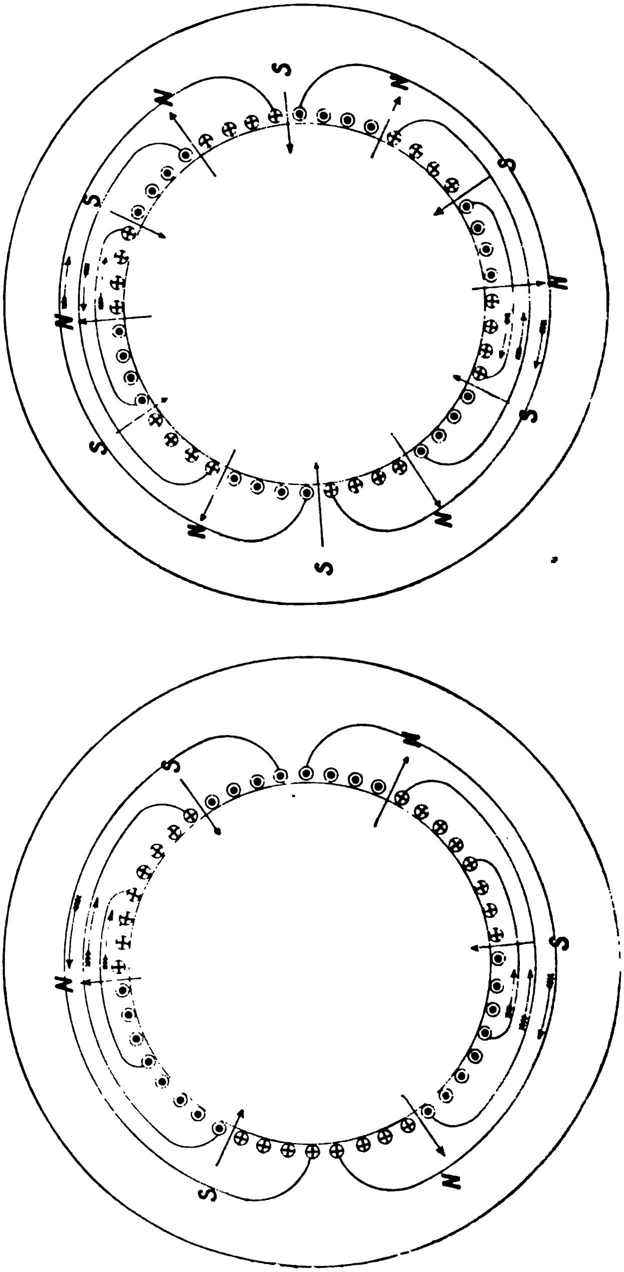


FIG. 17.

pole to eight-pole stator, and Fig. 17 that for a six-pole to twelve-pole, to which the same remarks apply. The manner of carrying out the stator winding for the last case actually employed is illustrated in Fig. 18.

For polyphase motors, exactly the same winding arrangements are used, applied of course to each phase. For these

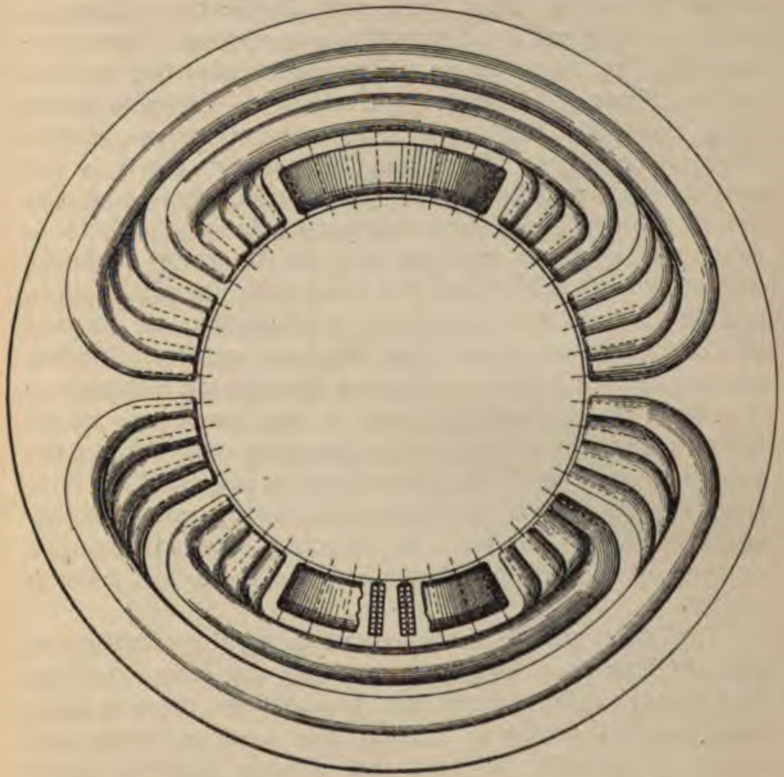


FIG. 18.

motors, if more than one change of speed is desired, the controllers get somewhat expensive, and it is therefore better on the whole in such cases to combine the method with rheostatic (rotor) control, the rheostat being used for the intermediate speeds only.

For small motors having squirrel-cage rotors, no modification of the rotor winding is needed; but where wound rotors are employed the general method of rotor winding

is illustrated in Fig. 19, which illustrates the single-phase case for simplicity. The general principle is to so arrange the windings of each phase, that they are formed of a number of sections in parallel; with a certain number of poles, the E.M.F. of one section will neutralise that of another section in parallel to it, and a current will flow through the sections only when they are externally short-circuited; on the other hand, with double the number of poles, the external short-circuit is superfluous. Thus consider Fig. 19, representing (diagrammatically) the winding for one phase of the rotor for a two-pole—four-pole stator. Each phase has two sections, permanently short-circuited one on the other. At starting, the stator switch is put over to the two-pole position, and the slip-rings gradually closed through the starting resistance. So long as the slip-rings are open, no currents flow in the rotor windings, as the induced E.M.F. has the same value in each section, and the two E.M.F.s neutralise one another, on account of the two stator poles. But the rotor currents circulate as soon as the rings are connected through the resistance—this latter is gradually cut out in the usual way as the motor comes up to speed. In changing over now to the four-pole position (if the lower speed is required) the slip-rings are not wanted, as the two sections are now in series, with the E.M.F. in the same direction, and so the rotor currents can circulate independently of the external short-circuit.

The same general arrangement is used for motors to run at more than two speeds. Here the rotor windings (per phase) can have more than two sections, these sections being wound partly to overlap one another, while still being in parallel, so that the various E.M.F.s partly neutralise one another, and partly add themselves together. With this arrangement, the same rotor winding can be effectively used with a stator having several different arrangements of the poles—that is, for a motor running at several distinct speeds.

For induction motors having rotors with star-connected three-phase windings, which is the practical case, only three slip-rings are required, the (second) common junction being at the three slip-rings, as usual.

In the workshops of the author's firm, where many of

the tools are driven by three-phase motors, the Heyland method of speed regulation is employed with great convenience. Several of the larger tools (such as planing machines and the like) are driven by independent three-phase motors wound for two speeds, the alteration of speed

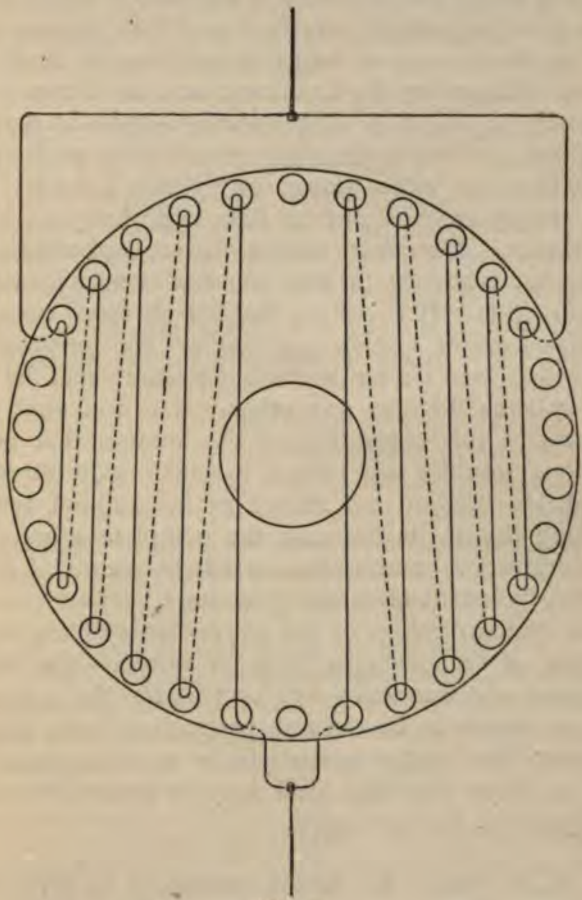


FIG. 19.

being effected by throwing over the reversing switch. It has been found by tests on these motors that the power-factor is diminished very little by the increase in the number of poles, attaining a high value at both speeds, while the efficiency is also high at each, there being but slight loss of *energy involved by the* change-over. At the same time,

the increase of first cost with the two-speed motors is very small.

Concluding Remarks.

Although the author has dwelt at some length upon the subject of single-phase motors, it has been more on account of the technical interest attached to it than because of any belief in the present or future possibilities of single-phase systems. Regarding the Continent and the States it is not too much to say that single-phase supply is practically played out, and that engineers responsible for putting down new stations for either power or lighting consider single-phase supply systems out of date and their employment bad practice. Moreover, indications are not wanting that the present tendency in this country is to follow in the same direction. It is certain that for all those cases *where continuous-current systems are out of the question* every requirement can be far more successfully met by three-phase systems than by any other. It is true that certain engineers in this country hold the opinion that pressure regulation troubles are bound to occur with three-phase working (an opinion not shared by the author), but, even supposing this to be the case, the complete solution is to hand—convert to continuous current by means of rotaries, or better, by means of motor-generators.

The standardisation of the above two systems, together with that of two voltages for each system—220 and 440 volts—and one frequency—50 cycles—for the supply networks, is greatly to be desired, particularly from the point of view of the motor manufacturer and the motor user. With the hope that this ideal may be eventually realised, this paper can be concluded.

Mr. Field. Mr. M. B. FIELD: Mr. Eborall commences his paper with an apology for bringing before the Institution one which he says contains but little that is really new from the technical point of view. Now I venture to think that this apology is quite unnecessary, for I believe I am right in saying that many of the ingenious devices which Mr. Eborall has explained to us to-night, although perhaps not new, are new to many of us: at any rate, they were to me. The paper contains a large amount of information which is extremely useful, as well from the manufacturers' as the users' and theorists' points of view. The method of building up the stator core described by Mr. Eborall,

Mr. Field.

whereby all tooling is rendered unnecessary, is very interesting. But it is to be pointed out that one has to depend entirely upon the friction between the individual plates to avoid displacement of the same, or rotation of the stator core as a whole. Where paper insulation between the core discs is employed, some 15 per cent. of the total space will be thus occupied, and with the continual heating and cooling of the motor this may shrink, and thus tend to relieve the friction between the end plates; consequently for large-sized motors this construction is not suitable. The question of tooling the stator cores is very important, but it is not very important whether the rotor core be tooled or not. The slip is very small, and hence the eddy currents produced in the rotor surface will likewise be small; moreover these will not be detrimental, but will add to the torque rather than decrease it. The figures on page 813 are very instructive, but I would suggest that the author adds in his paper when printed in the Journal the corresponding figures for continuous-current motors. I know this does not exactly fall under the heading of the paper, but a comparison would be so very interesting that the departure would be quite warranted. The comparison between the efficiencies of polyphase and single-phase motors is also noteworthy. We must remember that a given rotor developing a given H.P. has twice the C^2R rotor loss if in a single-phase field, to what it will have in a three-phase field of the same strength;

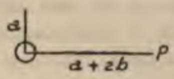


FIG. A.

so that in order to get high efficiency in the single-phase case one can only do so at the expense of extra material, which fact, I think, is borne out by the table of weights given on page 814. From this it appears that the weight of the single-phase motor is about 50 per cent. higher than that of the corresponding polyphase motor.

I should like to make a few remarks with regard to the starting of the Heyland motor, as it seems to me that this is a radically new departure. I have always been under the impression that it was of no advantage to make the starting field larger than the working field, the aim of the manufacturer being to obtain as nearly as possible a pure rotating field at starting. This, of course, is not the case, as is easily seen by the following diagram. Let a be the strength of the alternating flux produced by the working phase winding, and $(a + 2b)$ the corresponding flux produced by the starting winding. Suppose these two fluxes are in quadrature both as regards space and time. If we combine the working phase flux a with a portion of the starting flux equal to it in magnitude, we get of course a rotating flux of strength a, and superimposed upon that an alternating flux of strength $2b$ in the direction OP. Now, this latter flux we may consider replaced by two rotating fluxes, each of strength b, rotating in opposite directions with the same velocity, viz. that corresponding to the frequency. Further, these two fluxes b will coincide and be directed along OP at the same

Mr. Field. instant that the rotating flux a lies in this same direction; in short, the resultant of the working and starting winding fluxes will be a forward rotating flux of strength $a + b$, and a backward rotating flux of strength b. When the motor is starting the speed of rotation of these two fluxes is the same, and since each pulls on the rotor, the one forwards and the other backwards, with a force proportional to the square of *itself*, we get for the resultant starting torque an expression proportional to $(a + b)^2 - b^2$ or $a\ (a + 2b)$. In other words, the starting torque is proportional to the product of the two fluxes, which shows us at once the advantage to be gained by making the starting flux large. If the two fluxes are not 90° out of phase with one another, but differ by the angle ϕ, then the starting torque is proportional to $a\ (a + 2b)\ \sin\ \phi$. Mr. Eborall says that in the Heyland motor ϕ may be 50°; assume it to be only 45°, then we see it is only necessary to make the starting flux 1·4 times the working flux in order to obtain precisely the same starting torque as would be obtainable in the corresponding two-phase motor.

We may say briefly, if A and B be the working and starting fluxes respectively and ϕ the phase difference, they represent, as far as their starting capabilities go, a rotating flux of strength $\sqrt{\mathrm{AB}\ \sin\ \phi}$

With regard to the method of winding the Heyland motors for the purpose of altering the number of poles, it seems to me that the paper is not quite clear. Mr. Eborall says: "On the other hand, the method of altering the number of poles has two serious disadvantages. Firstly, the reduction of the number of poles causes an unfavourable distribution of the magnetic flux, a large increase of magnetic leakage and a loss of winding space. This is of course owing to the fact that after the reversal of the appropriate coils the currents flowing down one side of those coils are neutralised by the currents in the adjacent side of the unreversed coils, as will be readily seen from Fig. 14, illustrating the single-phase case." Now this is not necessarily so: at least it is entirely a matter of arranging the winding so as to have as many coils as poles, or as many coils as pairs of poles. In Fig. 14 we have four coils, that is to say, we have as many coils as poles, and that is the reason why part of the winding is neutralised when the two coils are reversed. If we change that winding and put as many coils as pairs of poles, making two coils instead of four, we shall find the windings are not neutralised when we reverse one coil. Fig. 16 shows this very well. This winding is not particularly a Heyland winding, but merely a normal winding with as many coils as pairs of poles. On the right-hand side there is an eight-pole winding with four coils. When we reverse two of the coils we get four poles. The Heyland winding corresponding to Fig. 18 for that case would be as shown in Fig. B. Fig. 18 shows a twelve-pole winding. If the connections of the coils be altered, we can get a six-pole or a four-pole or a two-pole winding. In the above diagram we can get an eight-pole, a four-pole, or a two-pole winding by similarly altering the connections between the coils. Fig. 16, on the other hand, shows an ordinary winding which has been known and employed for a very long time. It differs from the Heyland arrangement in that the only variation possible is 8–4 poles. We have, in fact, as above stated, an eight-pole winding

with as many coils as pairs of poles. We can therefore reverse half, and get half the number of poles with none of the windings neutralised, thus obtaining as many coils as poles. If we were again to reverse half the poles, half the winding would be neutralised. The only variation feasible is thus from eight to four poles. That is the main difference between this and the Heyland winding shown in above diagram. Mr. Field.

Mr. LANGDON DAVIES: There are one or two matters which I should like to refer to. On page 809 the author says, "With single-phase motors which are usually arranged to start up light, wound rotors with slip-rings should be used over $7\frac{1}{2}$ B.H.P.," but he does not appear to give any explanation why this should be. I have seen larger sizes without them, and should therefore be obliged if the author would kindly give his Mr. Langdon Davies.

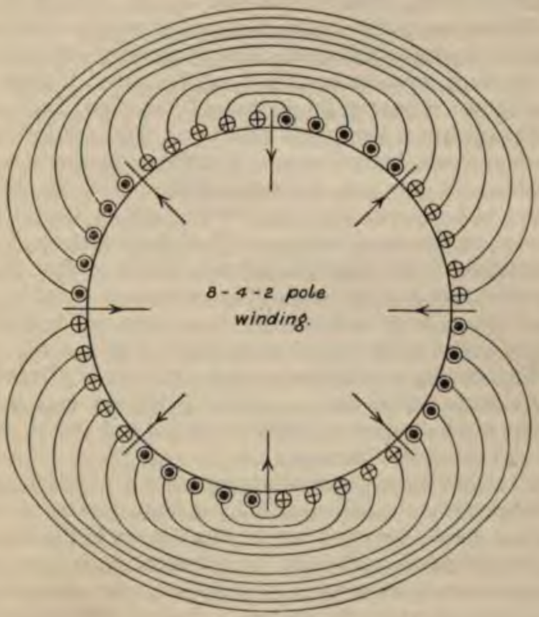


FIG. B.

reasons. With regard to one particular type of motor the author says, "The winding carrying the current of greater phase difference is made to have the smaller self-induction." I do not understand, considering that there is nothing exterior to the coils, what produces the "greater phase difference," if it has the smaller self-induction. It may be that he and I attach different meanings to the term "self-induction." Later he says, "The production of a rotary field on starting is not aimed at." This appears to require explanation, because a rotating field is absolutely necessary to start an induction motor of the type described. Also a considerable phase difference, I believe 50° or more, is claimed *later on.* The form of stator winding described is interesting and

Mr. Langdon Davies.

appears to save turns. I should like to know if the author can give any details of starting torques for given current values without any resistance in the rotor; that is to say, with an ordinary short-circuited rotor of any type. These would be interesting, as they would show the difference produced by this stator winding, irrespective of the addition of resistance to the rotor windings, which is not new. The paper is an exceedingly interesting one and raises many points for discussion.

Mr. Rhodes.

Mr. W. G. RHODES: I have listened with very great interest to Mr. Eborall's paper. It deals with a subject which has not for some time been brought before the notice of the members of this Institution, and one which certainly deserves more attention than it receives in England. It is, in my opinion, a subject which will eventually have to engage our attention, whether we will or no. There are, as Mr. Langdon Davies has pointed out, some rather peculiar remarks in the paper which require elucidation. One regarding self-induction, on page 821, perhaps may be explained in this way. I think that Mr. Eborall is rather misusing the term self-induction, because, in my opinion, the coil has a *larger* self-induction. The self-induction of a coil when there is another coil near to it is the number of lines of force which link that coil only and escape the other. Now Mr. Eborall distinctly states in his paper that the starting coil is wound in such a manner as to produce large leakage. That large leakage, I take it, is the self-induction. The Heyland motor is wound so that the running coil has a minimum leakage—no self-induction—if possible, while the starting coil has a large leakage, that is, a large self-induction. The reason why a better result should be obtained with a small number of turns on the starting coil is that a larger current is allowed to pass, producing a large useful flux, or mutual induction, and at the same time a large self-induction to displace the current out of phase with the impressed potential difference.

I prefer to view these problems rather from a physical aspect than from a mathematical one, although I have often looked at them from both points of view. On page 815 the flux density in the iron is given; I imagine that it is rather too high. In transformers it is not customary to go up to 10,000 lines or even to 5,000 lines per square centimetre, on account of the large hysteresis loss. An induction motor is like a transformer, and the stator is subject to the full frequency of the supply circuit, so that, in order to keep the efficiency of the motor within reasonable limits, it is advisable to keep the induction density moderately low.

With regard to Mr. Eborall's statement as to the standardisation of periodicities and voltages for alternating-current motors, one cannot say too much in favour of it, because the want of such standardisation is undoubtedly the manufacturer's bugbear.

As to the possibility of starting monophase induction motors under load, it seems to me that too much attention has been devoted to the stator windings. Undoubtedly the Heyland winding is an extraordinarily good one; we will not dispute that. It produces good results. We are told that the phase difference between the starting

current and the running current is about 50°. The two mutual fluxes, Mr. Rhodes the mutual flux of the running coil and rotor and the mutual flux of the starting coil and rotor, should approximately produce a uniform rotating field. The leakage flux of the starting coil should displace the current in it as much as possible, the nearer 90° the better, though of course this value cannot be attained, but the greater the displacement of phase the better it is for starting.

If further improvement is to be made in the starting of such induction motors, we shall have to look to the rotor. The Heyland motor is, as far as the rotor is concerned, worked by inserting at the start a resistance into each of the three circuits. The object is to cut down the rotor currents at the start, because the rotor itself has a large self-induction, producing a large leakage field—a large field which does not cut the stator running coil. The insertion of resistance into the rotor circuits diminishes the leakage field, which, by its demagnetising action, tends to nullify the effect of the stator magnetising current, but it also diminishes the rotor energy current, which is in phase with the E.M.F. induced in the rotor coils and which produces the torque. What we ought to do, if possible, is to wipe out the self-induction of the rotor coils completely, in fact to have no self-induction of the rotor coils, no self-induction of the running coil, and a large self-induction of the starting coil. It is impossible to wipe out the self-induction of the rotor coils by means of a non-inductive resistance to start with, and to put in an inductive resistance to start with is worse, because that will throw the current more out of phase with the induced E.M.F. I have tried myself to nullify the effect of the leakage field due to the rotor currents themselves by the injection in the rotor circuits of counter E.M.F.'s which will act in opposition to the leakage field produced by the rotor currents, and I have got very fair results from it. For instance, I have got a motor to start with full-load torque with approximately $1\frac{1}{2}$ times full-load current. That is not very good, but it is fairly so, and may probably be improved. I have now in process of manufacture by the Clayton Engineering and Electrical Construction Company, Ltd., a two-horse induction motor for 50 cycles and 200 volts, and I am anticipating that the starting current will not much exceed 13 amperes. The counter E.M.F.'s are obtained by tapping the stator circuits in a suitable manner and connecting through a suitable switch with the rotor collector rings. It can be done by using transformers with negligible leakage.

The necessity of having little or no self-induction of the rotor coils and running coil is obvious when we consider the low power factor of alternating-current motors. When we cannot get more than about 75 per cent. power factor, it shows that the leakage is considerable.

We cannot consider the alternating-current motor, either polyphase or monophase, anything like perfect until we can have at the same time a frequency changer. The present method of changing the speed is altogether crude and unscientific. It does not admit of any gradual change of speed at all. It can jump from one speed to another and back again suddenly, but the gradual change of speed is impossible with the present means. The only means of doing that

r. Rhodes.

and of obtaining the results which we hope to do with induction motors, is by the introduction of frequency transformers giving a very wide range of frequency.

rofessor . Wilson.

Professor ERNEST WILSON: Mr. Hurst has prepared some curves for me which are shown in the accompanying diagram. The data from which those curves have been obtained were supplied to me by well-known manufacturers of induction motors. In the diagram vertically the weight of the motor, suitable for belt driving, is given in pounds, without reckoning foundation rails, starting resistances, or anything external to the motor. Horizontally is plotted a quantity which I once ventured to call a "mass-factor,"[1] that is to say it is the B.H.P. of the motor divided by the revolutions of the motor per minute. The

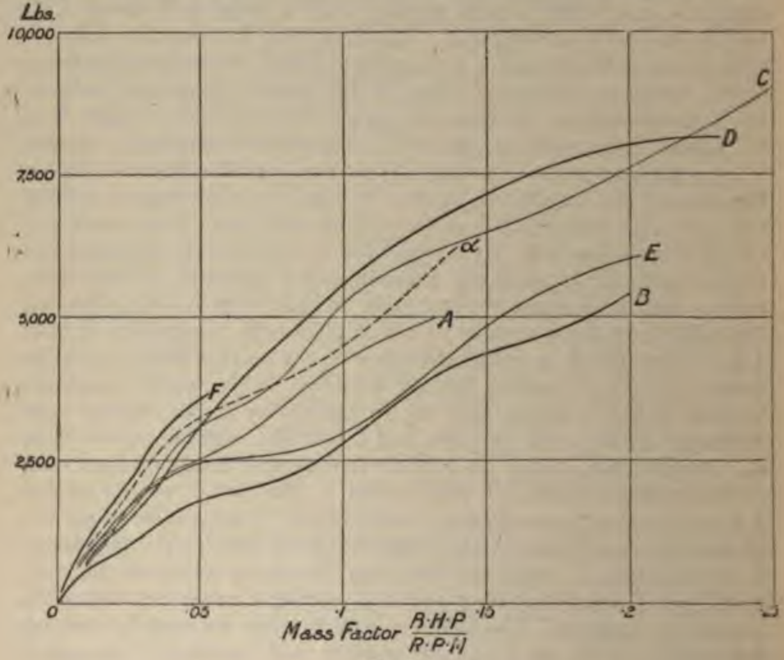


FIG. C.

curve A refers to a single-phase motor suitable for working at a frequency of 50 periods per second; the curves B, C, E and F refer to multiphase motors at 50 periods per second; whilst the curve D refers to multiphase motors at 60 periods per second: the data being such that the curves are comparable with one another. The dotted curve α refers to direct-current four-pole motors made by a well-known firm, and is included for comparison with the curves which have been obtained from the induction motor data. I should like to point out that different makers have widely different ideas as to what the weight of a motor should be for a given mass-factor. For instance, taking a mass-

[1] See *Proc. Inst. Elec. Eng.*, part 127, vol. xxvi. p. 160.

factor of 0·1, the weight may vary through very wide limits, according to the ideas of the several makers; and this, I think, is an important matter. The prices of these motors have been plotted in terms of the mass-factor. I have not got the diagram here, but there is not such a great difference between the prices as there is between the weights. In conclusion, I wish to congratulate Mr. Eborall on presenting such a valuable paper. Professor E. Wilson.

Professor C. A. CARUS-WILSON: The most interesting part of this paper is that relating to starting devices for single-phase motors. I have endeavoured to make out from Mr. Eborall's paper exactly how Mr. Heyland's device works, but it is not easy to ascertain what is the real action producing this result, and the difficulty is increased by the way in which Mr. Eborall uses the word "self-induction." The problem of the single-phase induction motor point is to get a strong field lagging well behind the primary field. One way in which this has been attempted is, as Mr. Eborall has indicated, to use an outside choking coil. The disadvantage of this method is that while you get a good lag you waste your field; that is to say, the flux in the choking coil is no use for producing torque, or, as Mr. Eborall puts it, "the strength of the cross flux, *in the motor*, is diminished by an amount equivalent to the leakage flux of the coil." If, on the other hand, you try to get your lag by using a starting coil of large self-induction, you find that the effect of the self-induction is neutralised by the reaction of the currents in the rotor, so that you have a strong field but a poor lag. What Mr. Heyland has done is practically this. He has taken a single-phase motor with the usual starting coil and no outside choking coil, an arrangement which, under ordinary circumstances, would give you hardly any starting torque, and he has allowed some of the useful flux of the starting coil to leak, by providing it with a carefully designed leakage path, and this leakage flux is enough to give a good lag. It is true that by permitting leakage he weakens his field, but in doing so, he gets a field out of step with the torque-producing field, and in that way he is able to get a good lag. I think that the real discovery Mr. Heyland has made is that it pays to take away part of the total field of the starting coil, when by so doing you can make it leak and thus get a good lag. As to the reason why it is found advantageous to have but few turns in the starting coil, it seems to me simply a question of ohmic resistance, since by lowering the resistance you can increase the lag that you get for any given self-inductive effect. Mr. Heyland has certainly obtained good results, that is to say for single-phase motors, namely, a full-load starting torque with twice the full-load current. Looking at the diagram on page 811, one sees in the first place that the speed regulation is good for a motor of that size: in fact the speed regulation of a single-phase motor is in general better than that of a polyphase motor. The efficiency is very fair as shown by the diagram. The great defect is, no doubt, the low power factor. Few things are more provoking to the electrical engineer than lagging current. One feels that it is not doing the least good, and yet you cannot get rid of it. Of course with a single-phase induction motor all the bad effects due to lagging currents that you get in the polyphase motor are intensified, since the primary current Professor Carus-Wilson.

Professor Carus-Wilson.

has to carry the magnetising current for both the main field and the cross field, and consequently you get a very low power-factor, as shown in the diagram, something between 50 and 60 per cent. at half load. Electrical engineers have made great efforts to increase the value of the power factor. In this connection it is difficult to avoid mentioning the name of Mr. Steinmetz, the Clerk Maxwell of alternating-current engineering, since it is almost impossible to say anything about induction motors that has not been written or said by Mr. Steinmetz. It is not, I think, out of place to refer to the remarkable discovery—as I think it may be called—quite recently made by Mr. Steinmetz of the single-phase condenser motor. In the course of experiments Mr. Steinmetz found that if in a single-phase induction motor you connect the starting coil, called by him a tertiary coil, to a condenser, of suitable capacity, it can be made to supply the magnetising current for the cross field, thereby relieving the primary of the burden of supplying that current, and thus raising the power factor to that of an ordinary polyphase motor. Further, by increasing the capacity of the condenser, not only can it be made to supply the magnetising current for the cross field, but also that for the main field. In this way the condenser actually supplies the whole of the magnetising current, and the power factor is raised to one hundred per cent. It is true that this gives no advantage at starting, it simply enables you to run at synchronism with a high power factor. Mr. Steinmetz gets his starting effect by shifting the tertiary or starting coil round through a certain angle; this seems to have led him to the idea of applying this method to an ordinary three-phase motor, that is to say, simply to put the condenser across one of the three-phase connections. In this way he gets a good starting effect—though not as good as when the motor is running on a polyphase circuit. Not content with putting a condenser coil across one of his three-phases, he puts a reaction coil across the other, and finds that he is able in this way to make the starting torque and the output of a single-phase induction motor as high as could be obtained if the motor were running as a three-phaser and at the same time with a power factor at synchronism of over 97 per cent. I think that is a remarkable result. It will be said that with this system you have to use condensers, and that there are serious objections to this. No doubt there are objections to condensers, but like many other objections they may perhaps be got over. In any case I think Mr. Steinmetz may be congratulated upon his achievement.

Mr. Ferranti.

Mr. S. Z. de Ferranti: I have followed this paper with the greatest possible interest, but the concluding remarks interested me even more than the paper, because in them the author says that single-phase supply is practically played out. Well, if that is so, I think it is a very great pity to have taken up the time of one of the Institution's meetings with a paper about single-phase alternating-current motors. So far as I can see, single-phase alternating supply is only just commencing, provided it is carried out in the right way. I do not say that to-day for a large power scheme I should feel inclined to lay down a single-phase system, but I feel confident that in less than a year's time we shall be planning single-phase power schemes for all purposes. Indeed, to-day it would

be very hard to get anything better than a single-phase power-supply for feeding a continuous-current network. I think it would be found the cheapest way of doing it through motor-generators, and I think it will be found the most efficient and generally the most satisfactory way. For town lighting, where there is a fair amount of motive power work, very excellent motors, among them that of Mr. Heyland, have made this quite a practical system, and there is very little superiority of the continuous-current for ordinary motor work over a low periodicity alternating. There is, of course, the question of running lifts, and motors of that class still require a satisfactory solution. I am, however, quite confident, and that apart from what we hear that Mr. Steinmetz has done, that there will be before long commercial single-phase motors on the market with a power-factor of very nearly unity, and an efficiency of about 90 per cent., or even more, in ordinary practice. With regard to what we have heard about Mr. Steinmetz, it seems strange, since the problem is solved, that we do not see the result of the solution on the market. As a matter of fact, I do not think Mr. Steinmetz was at all original in the work that we have heard attributed to him. Who really started this idea I do not know, but I saw eight or nine years ago a motor fed on a single-phase circuit running practically as a two-phaser and using a condenser on one circuit which gave all the results that we have heard of, and yet that motor is not on the market. I suppose the reason is because one of the elements, the condenser, is commercially wanting. If we had the condenser it would settle a great many problems and improve a great many rather awkward positions. No doubt the demand will bring forth the article sooner or later, and I hope sooner. With regard to the question of single-phase motors as applied to the production of power in cities, ordinarily, I think that engineers running single-phase installations need not feel in the least uncomfortable or anxious about the future of their installations, provided they are of low periodicity. We have heard, as I said before, that this class of work is played out; but, on the other hand, I think this class of installation is just commencing its real career of usefulness. Still, I would like to point out that high-frequency installations are at a very great disadvantage, and whatever improvements are made in the way of motors and in the way of running these systems generally, I do not think that they will ever get to be as satisfactory commercially or as good generally as low-periodicity single-phase systems. There is no doubt that the low periodicity greatly assists the motor question besides many other questions, and I think that when we have got the few additional developments which are still wanting we shall see the bulk of power-supply and distribution work done with single-phase alternating currents. Mr. Ferranti.

Mr. W. B. Esson: The large attendance at this meeting shows the great interest which is being taken in induction motors, and Mr. Eborall is to be congratulated on bringing this subject before the Institution. But in the short time at our disposal the matter cannot be discussed in the way it certainly deserves. I should like to say that I appreciate in the highest degree a remark made by the author at the end of the first Mr. Esson.

Mr. Esson. part of the paper, where he says "that experience in designing and a large quantity of experimental data for the type in question are absolutely necessary if the best results are to be obtained." If you devour the whole literature of the subject the feast will not enable you at the first trial to design a good induction motor, and I think every designer knows that. Coming to the points of construction, I am very interested in Mr. Eborall's way of building up the stator plates, but there appear to be some disadvantages which Mr. Field has already alluded to, and which may become accentuated in motors of large size. In the motors my firm has made we have fitted the plates right into the cast-iron stator cases. We find that we cannot dispense with the tooling, because the stampings are not good enough to enable us to have a uniform gap of $\frac{1}{64}$ in. with plates of 12 in. diameter, without tooling inside. Mr. Eborall puts the matter in this way. He says: "I cannot use the hole stampings, because if I do I have to tool them, as the shred of iron left must be very small." On the other hand I put it this way: I have to use the hole stampings for small motors, because there is no other kind I can tool. If I have slotted stampings they cannot be tooled, because they burr up. There is a question in my mind as to whether the stators with the straight slots, as made by the American Companies, notably the Westinghouse Company, or the stators with the hole winding made by the Continental firms, are the best. The one has certainly all the coils wound on formers, and you get a perfectly symmetrical winding, and a winding, I think, which should be easier to repair than the hole wound stators, where you have bent coils and straight coils alternately. It is a very important point in sending motors abroad, where no technical skill can be found—or at any rate the technical skill is of a very low order—to have motors that require no repair, or very little repair; and when they do want repairing the repairs ought to be able to be performed in the easiest possible way. On page 808 Mr. Eborall refers to the starting of the motors, and he says: "For motors having to start against load (apart from crane, elevator, and mining motors) the author is decidedly of opinion that the squirrel-cage construction, or its modifications, should be avoided with all polyphase motors about 5 B.H.P." That, I believe, is the Continental practice. Motors with squirrel-cage windings are not usually made above from 5 to 10 h.p., though I have got some firms to make them as high as 22. On the other hand, the American practice is quite the reverse. There they make motors of any size, with squirrel-cage windings. The largest I have had was from the Westinghouse Company, a 50 h.p. with squirrel-cage winding, and it gave every satisfaction. I should like to hear more fully the author's reason for limiting the size of the motor with a squirrel-cage winding to such a low power as 5 h.p. It must be remembered that a wound rotor is much more expensive. In the case of a wound rotor you want probably four times the amount of copper to get the same result, and with the wound rotor you have a somewhat smaller power-factor. Coming to the figures which Mr. Eborall gives of the performance in "Notes on Performance and Design," in my Society of Arts paper, read in 1897, I gave some figures of the power-factor. These were not the same as those of Mr. Eborall, and they differ in

this way, that Mr. Eborall's figures are, I understand, guaranteed performances, whereas mine were actual performances. There is a very great difference. I have had the figures for power-factors, which Mr. Eborall gives specified and also guaranteed, but I have never got them. I can tell you what is given by the very latest and best practice on the Continent. I have had an opportunity of testing all sizes of two-phase motors, from 5 h.p. up to 100 h.p., and the very best power-factor we ever got with a 15 h.p. was 81 per cent. (that was with a squirrel-cage winding); with 25 h.p. 78 per cent., and with 100 h.p. 80 per cent. They were two-phase motors, with a frequency of 50. While therefore I am a great believer in the induction motor, I am no believer in Mr. Eborall's figures. That, I think, is all I have to say on the motor question. There is one point which has been referred to by Professor Carus-Wilson, namely, the question of condensers. I should like to hear from Mr. Eborall whether latest advices from the Continent and America on the subject show condensers to be commercially successful. Several years ago the Stanley Manufacturing Company in the States introduced as an ordinary thing in their catalogues condensers for working with two-phase motors, but I never heard whether they had been successful commercially or not. I should very much like to have some information upon that point. Mr. Esson.

Mr. G. L. ADDENBROOKE : I think Mr. Eborall is to be congratulated on the manner of his paper, as well as the matter. It seems to me that he has presented the whole subject in a very well-balanced way. There is one point with regard to the power-factor which I should like to allude to, following on what Mr. Esson has said. It appears to me that the wattless current taken by motors, though not actually constant, is more or less a sort of constant over a considerable range, and it would be very useful if in the figures he has given us Mr. Eborall could split up this no-load current into two factors, the watt current actually taken for friction and magnetising the iron, and the actual wattless current required to produce the field. These figures are very useful, because if you have that constant for no load it enables you to get an approximate figure for the power-factor for any other load. I do not say that it is absolutely so, because leakage comes in with a heavy current, but it certainly gives a very useful approximate figure. Mr. Addenbrooke.

The only other point I wish to deal with is the question of single-phase *versus* two- or three-phase. It is rather unfortunate, when we are proposing to open out into this work, that this question should be raised again. I have spent some time in looking into the matter from a practical point of view, and it seems to me that it is difficult to form any very definite opinion on the subject, as one cannot go on any very clear-cut lines. You can get up to a certain point, after which we must speculate upon unexpected developments of some sort or other. Mr. Ferranti may know something which he has not told us which might modify our ideas, but I must say I cannot see anything on the horizon which would in the end make single-phase better than a two- or three-phase alternating-current for most purposes. Supposing we actually succeeded in making a single-phase alternating motor as good as a two-phase motor—to all intents and purposes—should we have a very great

Mr. Addenbrooke. gain? Would it not still be better to have two or three phase? Are there not certain advantages in having two and three phase, I do not say in the motor itself, but in the whole system, which would outweigh a question of the apparent simplicity of single phase? That is the point.

Mr. Thomas. Mr. EUSTACE THOMAS: Mr. Eborall's paper has raised many points of interest, but it will only be possible at this late hour to refer to one or two of them.

The use of squirrel-cage rotors has been disparaged in a manner which is, I think, somewhat too general. There are many cases where a squirrel-cage rotor would produce objectionable disturbance even in a motor of only one or two horse-power. On the other hand, there are cases where such rotors can be used with advantage in motors of 50 horse-power or more. Perhaps the only generalisation that can be made is that squirrel-cage rotors should be used in all the numerous cases where no serious disturbance will result, and where the other conditions are suitable; the engineer will have to decide each case on its own merits. An engineer cannot afford to get the reputation of being a "wound-rotor man," or a "squirrel-cage man," any more than he should allow himself to be considered a "continuous-current man" or a "three-phase man." Each system should receive application in its proper place.

In his "Notes on Performance and Design," Mr. Eborall gives values which are, I think, more applicable to the closed slot, or Continental design, than to the open slot American type. The latter undoubtedly has a larger magnetising current, but it possesses the advantages of form-wound, interchangeable windings, and seems to give somewhat better results as regards breakdown point, efficiency, and power factor, although these do not depend only, of course, on the shape of the slots. In illustration of this I may quote the following tests selected at random.

The breakdown point of a 5 H.P. motor occurred at 2·7 times full-load current, and of a 50 H.P. motor at 4¼ times. Motors of intermediate capacities had values between. This is a matter of considerable importance, as the available torque varies as the square of the voltage, and such losses as commonly occur in distribution systems have frequently resulted in the motors failing to carry their load.

As regards efficiency, tests of a 5 H.P. motor showed 81½ per cent., and of a 15 H.P. motor 88·9 per cent. The 5 H.P. motor further gave a power factor of 87½ per cent. It may be that the values in the paper are guarantees, in which case, no doubt, a factor of safety has been allowed, and the difference would not be so great.

As further illustrating how motors of good design may differ, and still give good practical results, I may say that the air-gap on small motors may be larger, and on large motors smaller, than Mr. Eborall's figures with good results.

The preceding discussion has made it clear that the Heyland motor starts in the same general way as other motors commonly used, and it is unnecessary to dwell at length on the matter. To Heyland is due the credit of seeing that a large field produced by the starting coil is an advantage, and that sufficient lag can be obtained in the coil alone, by

bunching the windings and so shaping the slot that a considerable leakage path exists. Mr. Field's explanation of the value of the larger flux is new and interesting. Mr. Thomas.

The question has been raised by several speakers as to the possibility of using condensers commercially with single-phase motors. I am able to say that they have to my knowledge been used for some time past with success. After what has been said, the Institution may be interested to hear some of the results obtained on the commercial, as distinct from the experimental scale. A 5 H.P. motor gave a power factor of 90 per cent. and an efficiency of 80 per cent. It further started with full-load torque at 1½ of the full-load current. The advantages of the system both as regards starting and running will thus be apparent, and should make it possible to use such motors on existing lighting circuits having poor regulation on account of (magnetically) leaky transformers, or other cause.

Professor CARUS-WILSON: Was a re-actance coil used? Professor Carus-Wilson.

Mr. THOMAS: No. The motor may be described as a three-phase motor, the single-phase line circuit being joined direct to two terminals of the motor, while the third motor terminal was joined to one side of the single-phase circuit through a condenser. The condenser remains in circuit, and the motor with its condenser is treated as though the circuit were three-phase. In this case there is no starting coil to be cut out, but the whole of the winding is available both for starting and running, and hence the motor may be considerably smaller than the ordinary single-phase machine. This is of interest in relation to Mr. Eborall's remarks on the subject of size, and in that it enables the cost and weight of the motor and condenser combined to be kept within limits. The shipping weight of a 5 H.P. motor with all starting gear was 610 lbs., but this contained a considerable proportion of packing, probably about 20 per cent. The advantages of good power factor, efficiency, and starting are thus obtained without extravagant weight or expense. Mr. Thomas.

The system of Speed regulation described enables the speed of the motor to be doubled, but intermediate values must be obtained by resistance in the rotor circuit. I have the results of tests made on motors with a variable number of poles some time back, and it is evident, as might be expected, that the constants of the motor suffer. In the cases that have arisen in my own practice, a speed range of two to one has usually been the extreme limit, and the limit speeds have been seldom required, the motor usually running at some intermediate value. This unfortunately greatly moderates the value of variable pole speed control; but within their limited field of application, the devices of Mr. Heyland are ingenious and command respect.

Mr. A. C. EBORALL, in reply, said: I have to thank the various speakers very heartily for the honour they have done me in discussing the paper, and for their appreciative remarks. Several questions of considerable interest have been raised, and regarding these I would like to reply as follows:— Mr. Eborall.

Mr. Field thinks that the method of building up the stator core-discs *of induction motors*, employed by my firm and described in

Mr. Eborall. the paper, may prove objectionable on account of the plates working loose under the continual heating and cooling to which they are subjected in the motor. I think Mr. Field will agree that his objection entirely disappears when I tell him that the rivets are put in hot. As stated in the paper, however, the method is not so suitable for very large motors, and modifications are introduced for motors above 30 B.H.P.; up to this size it has proved thoroughly satisfactory, and several hundred motors so constructed have never given the slightest trouble. Mr. Field suggests that I should give some figures for direct-current motors relating to design and performance, for purposes of comparison with the induction motors. It is a little difficult to do this, because the figures for various makes of direct-current motor vary enormously, on account of the variation in design; with induction motors this difficulty does not come in to anything like the same extent, as the general design is practically the same with all makers. But I may say that, generally speaking, the efficiency figures guaranteed by different makers for semi-enclosed direct-current motors are about the same as those given in the paper for polyphase motors, and the same remark applies to the heating. But the overload capacity is much less, and the weight per B.H.P. considerably greater for such motors, compared with the figures for polyphase motors.

I am sure we are all indebted to Mr. Field for his very clear proof that in order to get the greatest possible starting torque with a single-phase motor, it is necessary to make the flux of the starting coils much greater than that of the running coils, and that it is not necessary to aim at the production of a uniform rotating field at starting. Mr. Heyland arrived at this result in quite a different manner, his method being not nearly so simple as that of Mr. Field, but it is curious that this important point should have been missed by every other designer of single-phase motors. Mr. Heyland saw some years ago that the idea of two equal fluxes at starting was fundamentally wrong, because the current in the starting coils of the single-phase motor cannot be made by any known means to have a lag of anything like 90° (as with the second phase of a two-phase motor), and he proved that by allowing the starting flux to be stronger than the flux of the running coils by a definite amount, it is possible to imitate the starting conditions of a two-phase motor, which is, as Mr. Field says, a radically new departure in single-phase motor design. The result has been that the Heyland motors are far and away ahead of any other single-phase motor with regard to the value of starting torque obtained with a given current consumption. Mr. Field's remarks on the Heyland speed changing device are perfectly correct, and may serve to make that portion of the paper referred to somewhat clearer.

Mr. Langdon Davies asks for my reasons for stating that single-phase motors above 7½ B.H.P. should be furnished with slip-rings. My own experience in this matter has led me to this conclusion chiefly on account of the better starting and greater overload capacity (particularly the former) brought about by the employment of wound rotors and a non-inductive resistance. I have found that with a given single-phase stator winding, a wound rotor used in conjunction with a non-inductive

resistance will start and run up to speed with 12-20 per cent. less current than any pattern of permanently short-circuited rotor, and, moreover, owing to the better distribution of current in the bars of a wound rotor compared with that in the bars of a rotor of the squirrel-cage type, the overload capacity is considerably greater. Again, a rotor with a permanently short-circuited winding is far more likely to have dead points at starting when used in a single-phase motor, which is perhaps the reason why the current consumption is greater. Slip-rings (normally short-circuited) give so little trouble, and cost so little, that I certainly think wound rotors are preferable. I may mention in this connection that the Heyland motors have wound rotors and slip-rings in all sizes, that is, from ½–100 B.H.P.; and, also in reply to a question of Mr. Langdon-Davies, it has been found with these motors for 40, 50, and 60 cycles, that running up to speed without load, the starting current is ⅔ of the full-load current when wound rotors are used, and at least equal to the full-load current when the most carefully designed short-circuited rotors are used. In reply to the other remarks made by this speaker, I would say that the phase difference of 40–50 degrees for the flux of the starting coils is caused by the great magnetic leakage this flux has, compared with the flux produced by the running coils. The large magnetic flux of the starting coils (caused by the large current in this winding of few turns) mostly leaks along a definite path, and this leakage produces the above-mentioned phase difference. At starting there is very little rotary field, the field of the motor being more of the nature of a purely oscillating field, and the result is exactly as shown by the paper and by Mr. Field. Mr. Eborall.

In reply to Mr. W. G. Rhodes on the question of the action of the Heyland motor, and also to Professor Carus-Wilson's remarks as to this, I am aware that the explanation given in the paper is, to a certain extent, incomplete, but it had to be curtailed as the paper was getting unduly long. I am sure, however, that the ideas of most of those present to-night will be fairly clear on this subject, after having heard the remarks made by different speakers. The action of all single-phase motors and their starting devices can be looked at from several totally different points of view, and most of those who have gone at all deeply into the subject get perfectly clear ideas about it, which may be, and generally are, very difficult to put on paper in a few words.

Mr. Rhodes thinks that the values for the flux-densities given by me for induction motors are somewhat high. I put it forward, however—I think for the first time—that in order to get large overload capacity with induction motors, and particularly with single-phase motors, the flux-densities in the iron parts, particularly in the stator cores and teeth, should be carried to a very high value; the increased iron losses can be counterbalanced by allowing for smaller copper losses, but, as a matter of fact, the increase in the iron loss by forcing the material in this way (and using less of it), is not very much, at any rate not enough to affect seriously the efficiency at light loads. In my opinion the two most important points in the design of induction motors are the selection of the flux-densities, and the shape of the stator and rotor teeth, and it is more important to design the teeth properly

Mr. Eborall.

than even the air-gap. Regarding the point now under discussion, we have found by actual test on many single and polyphase induction motors of various sizes, that very much better results are obtained when the flux-densities in the teeth and cores are forced than when they are not, and you will notice in the motors shown to-night that there is wonderfully little magnetic iron in them. With these motors, the overload capacity is 50 to 60 per cent. with constant pressure at the stator terminals, and I think that those present who are used to single-phase motors of other types will agree that this large overload capacity is much more than they have been accustomed to, and that it is good enough. On the other hand, you may think that if this question of flux-density is really so very important, why do I not keep it to myself. My reply to this is that the fact of having the right flux-density in the iron does not necessarily mean that the motor will be good; a very great deal depends upon the arrangement of the iron parts, upon the proportioning of the teeth, etc., and regarding these things every designer has to make his own experience.

I am greatly interested to hear about Mr. Rhodes' recent work in single-phase motors, and look forward to seeing his motor on the market in due course. If this motor will really start with full-load torque, with a current not exceeding the full-load current, as indicated, and if this result is attained without excessive complication and cost, then the Rhodes motor will certainly be a very formidable rival to the Heyland motor, as this latter stands at present. But I may say that Mr. Heyland is continually making improvements, and even better results will be obtained in the immediate future.

Professor Ernest Wilson's curves are instructive, and with regard to them I would remark that in my opinion the curves B and E best represent good modern practice in polyphase motor building, and that the motors represented by curves D and C are unduly heavy for their output and speed. It is interesting to note from the curves that the line of direct-current motors whose weights have been plotted are heavier than the single-phase motors represented by the curve marked A.

I have already partly replied to Professor Carus-Wilson, and with regard to his remarks on the power-factor of induction motors I thoroughly agree. Most designers of these motors are constantly striving to improve the power-factor, especially at light loads, and in this connection it would certainly appear that Mr. Steinmetz has met with considerable success—at any rate in the testing room. Whether his method of shunting the windings by a condenser, which, by the way, is quite old, will ever prove of use commercially is open to question, as in my opinion a commercial way of building a condenser for continuous service has yet to be found.

Mr. Esson's criticism regarding the building-up of our stator cores has been already met; and regarding his remarks on the tooling of cores, while admitting that the difficulty of tooling stampings with open slots is a very real one, especially for the case of small motors, I must say that, in my opinion, it can be got over. Several Continental firms using this form of stamping invariably tool the stators in all sizes,

without burring the teeth, the only disadvantage being, as pointed out in the paper, a considerable increase in the iron loss. Mr. Eborall.

I agree with Mr. Esson's remarks on the subject of using former wound coils for stators and rotors, when the motors in question have to be shipped to places where skilled winders are at a premium, but for ordinary work I consider the employment of straight slots and former wound coils a mistake. You have to balance ease of repair and saving of labour in winding against a large magnetising current and diminished power-factor, especially at light loads, to say nothing of inferior starting, and in the great majority of cases the latter disadvantages outweigh the advantages.

With reference to Mr. Esson's remarks on the subject of permanently short-circuited rotors, I can only repeat what is stated in the paper on this point, and what I have already stated in reply to Mr. Langdon-Davies. At the same time, I cannot agree with Mr. Esson's statement that the use of wound rotors lowers the power-factor, and that such rotors require about four times as much copper as squirrel-cage rotors. The former is directly contrary to my experience, while the latter statement requires, I think, considerable qualification. With large induction motors, whose rotors are wound with a three-phase cylinder winding, the extra copper required is, at the outside, 50 per cent.

I am in complete disagreement with Mr. Esson's remarks on the subject of maker's guarantees, and regarding what he states to be the latest and best Continental practice in induction motor performance. Although I am perfectly aware that the guarantees given by certain firms are absolutely worthless, I am equally aware that those given by others are well on the right side. The figures given in my paper are, as stated, the average of the guaranteed figures of five well-known houses, one Swiss, two German, one American, and one Belgian, and the work of three of these firms is intimately known to me. Not only do I consider the figures in the paper perfectly reliable, but I maintain, and am prepared to prove, that better figures are obtained every day in ordinary work. Regarding the figures Mr. Esson puts forward for the power-factor of 50-cycle two-phase motors, as representing the latest and best Continental practice, I may say that I consider the figures quoted as being distinctly bad; I should certainly reject any 100-B.H.P. 50-cycle polyphase motor having a power-factor of 80 per cent. at full load. I may, perhaps, be allowed to say in this connection that I have recently put down two 100-B.H.P. two-phase motors in this country, which have a power-factor of 91 per cent. at full load; with these motors 90 per cent. was guaranteed, and 88 per cent. would have been guaranteed under penalty. So it would appear that Mr. Esson has been somewhat unfortunate in his selection of a manufacturer.

Regarding Mr. Esson's final remark on the subject of condensers, I can only say that I believe all condensers have been complete failures up to the present, when they have been used for continuous work. The great difficulty is with the heating, and consequent rapid deterioration of the dielectric, while they are bulky, heavy, and therefore expensive. On the other hand, liquid condensers give quite good results when used intermittently, such as for starting single-phase motors, but they, in

Mr. Eborall.

common with other types, are unmechanical, and consequently objectionable. Such liquid condensers quickly go to pieces if continuously in circuit; moreover, their capacity alters in an extraordinary way as they heat up.

I could say a great deal in reply to Mr. Addenbrooke, but will ask him to allow me to reply to his first remarks only, as the discussion of the relative merits of single-phase and polyphase hardly falls within the scope of the present paper. Mr. Addenbrooke asks me to split up the no-load current of an induction motor into its components, indicating the relative values of the two factors. I may say that for most well-designed polyphase motors of medium and large size, the watt component of the no-load current is somewhere about 10 per cent. of the wattless component. Thus, referring to the left-hand diagram in Fig. C (the triangle), C_W, the watt current required for friction, ventilation, hysteresis, eddy currents, and the small no-load copper loss, is 10–15 per cent. of C_M, the wattless magnetising current of the motor.

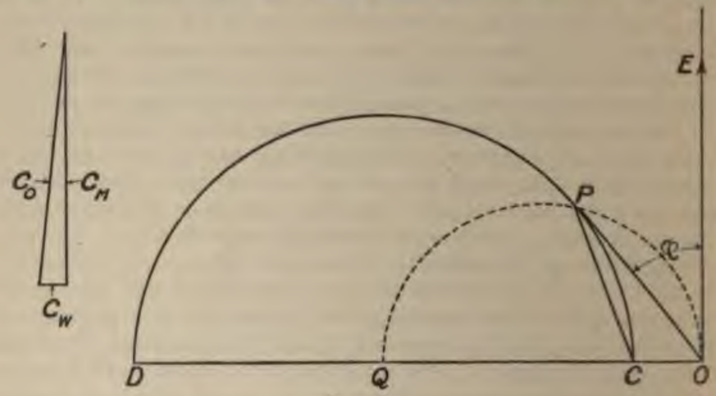


FIG. C.

The resultant of C_W and C_M, namely, C_O, is the no-load current of the motor, and this quantity is, as stated in the paper, 20 to 30 per cent. of the full-load current.

As Mr. Addenbrooke says, knowing the magnetising current of an induction motor (practically the no-load current), it is possible to predetermine the power-factor for any load. Fig. C illustrates an easy, graphical way of doing this, the diagram being constructed as follows:—

Let v_1 represent the stator leakage factor—that is, it is the ratio of the total magnetic flux produced by the stator ampere-turns to the flux that actually enters the rotor and cuts the winding *when the latter is open*. Similarly let v_2 be the rotor leakage flux—that is, the ratio of the total flux produced by the rotor ampere-turns to the flux actually entering the stator, and cutting its windings *when these are on open circuit*. Then write magnetic constant of the motor $= M = \frac{1}{v_1 v_2 - 1}$

v_1 and v_2 can be calculated, but are better found by a simple experi-

ment. Their value lies between 1·02 and 1·07 for most makes of motor. Mr. Eborall.

Referring now to Fig. C (which is the elementary diagram of the polyphase induction motor) set off the line O E to represent the phase of the applied E.M.F. per phase of the stator, draw the line O D at right angles to it and set off along O D the magnetising current to scale, namely, O C. Now multiply this value of O C by the above constant M, and make C D equal to the value so found, the scale being of course the same as that of O C. Upon C D describe the semicircle C P D. Then all such lines as O P (that is, any point along the semicircle joined to point O) represent the stator current per phase in magnitude and phase, and all such lines as C P are proportional to the rotor current. The corresponding power-factor of the motor is given by the cosine of the angle ϕ.

It will be seen that the maximum value of the power-factor occurs when the line O P is a tangent to the semicircle, as shown. For smaller and greater loads than corresponds to the value of stator current in question (O P), the power-factor diminishes, because the angle ϕ increases as the point P moves lower down or higher up the semicircle. The diagram clearly shows the effect of the magnetising current upon the power-factor of the motor, and also the effect of faulty design with regard to magnetic leakage.

With reference to Mr. Thomas's remarks, I think it would have been of interest had he told the meeting exactly what advantages are gained by building induction motors of large size with squirrel-cage rotors. Although I think with him that it is not possible to make hard and fast rules with regard to these things, particularly with regard to the relative merits of direct-current and polyphase working, still I think that after considerable experience with different conditions it is quite allowable to form and put forward an opinion. For instance, experience has conclusively proved that electric generators of any size should be direct driven, but it was not so many years ago that there was a very considerable amount of discussion on this point, and the early advocates of direct driving have now proved to be right. Regarding the point in question, it is clear to me that squirrel-cage rotors are inferior to wound rotors for all cases except those mentioned in the paper, and I am confident that American constructors will come into line with those of the Continent before very long in this respect. It certainly seems to me that the apparent simplicity of the squirrel-cage construction (or its modifications) and the resulting advantages have been greatly overrated. There is an example of this at the Paris Exhibition, where an 800-h.p. induction motor with permanently short-circuited rotor is being installed by one of the great American firms. This motor has to be run up to speed by a direct-current motor—a state of affairs bordering on the ridiculous.

Mr. Thomas's figures relating to the performance of induction motors confirm those I have given in the paper, which, being guaranteed figures, of course are well on the safe side, as Mr. Thomas surmised. I would like to draw Mr. Esson's attention to the figures for these American motors, as they fully confirm what I have already said when replying to him.

Mr. Eborall.

[*Added, July* 12, 1900.] When replying to the discussion on the paper I unintentionally omitted to reply to Mr. Ferranti, and therefore take this opportunity of doing so. I think if Mr. Ferranti were to reconsider his first remark, he would come to the conclusion that it is hardly fair. First, the paper does not deal exclusively with single-phase motors, quite half being devoted to polyphase motors; and secondly, I distinctly state that the part relating to single-phase motor work is put forward simply as being of technical interest. Many men, including myself, *have* to take up the question of single-phase motors and single-phase systems, not because of any belief in their present or future possibilities, but because it is necessary to do so; but at the same time, this does not prevent the subject from being technically interesting both to them and to others.

Mr. Ferranti's opinions on single-phase working are well known, and they are of the greatest value, because Mr. Ferranti has proved to be right on some of the most important points connected with alternating-current work many times before. At the same time, he does not give any reasons for his belief, and does not attempt to justify it in any way. But even with Mr. Ferranti's powerful championship of single-phase working, it is very difficult for those who have worked with single and polyphase systems to believe there is any advantage whatever in the former. Even in this country, many of the large single-phase systems are being converted into direct-current or polyphase systems, and all the most recent work of any magnitude is being carried out with either polyphase current, or a combination of this and direct current. My own opinion is that, as things are at present, continuous-current working is far preferable to any other for all large lighting schemes; and where it cannot be employed directly, it should be used, where possible, in conjunction with three-phase transmissions; or failing this, three-phase systems should be used throughout. For power work pure and simple, nothing can beat three-phase working, while for both lighting and power work, I am firmly convinced that the double-current generator (in combination with motor-generator sub-stations) has a great future—that is, a special combination of the direct-current and three-phase systems.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Associate Members :

Herbert H. Denton. | Victor Alessandro Mundella.
William Tatlow.

Associates :

James Hirst. | Bernard Pontet.
Thomas Frederick Johnstone. | George William Somerville.
Joseph Taylor.

Student :

Campbell Macmillan.

The Twenty-Eighth Annual General Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, on Thursday evening, May 24th, 1900 — Professor SILVANUS P. THOMPSON, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on May 17th were read and approved.

The names of new candidates for election into the Institution were announced.

The following transfers were announced as having been approved by the Council, viz. :—

From the class of Associate Members to that of Members—

Vernon Lindop.

From the class of Associates to that of Associate Members—

John Shaw Barnes.
Arthur Brunel Chatwood.
E. S. Curtis.
William Vyvyan Molesworth Popham.

From the class of Students to that of Associates—

Edward H. W. Partridge.
W. G. Royal-Dawson.
Ernest Vanderpoel Young.

From the class of Members of the Northern Society of Electrical Engineers to that of Associate Members of the Institution of Electrical Engineers—

Walter Leake.
T. Rowe.
R. Taylor.

Messrs. Leslie Dixon and H. M. Sayers were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Macmillan & Co., and to the *Benevolent Fund* from The British Westinghouse Electric and Manufacturing Company, Messrs. W. F. Dennis & Co., Messrs. Felten & Guilleaume, Messrs.

Creese & Sons, Messrs. R. Braham & Co., Mr. F. Trauffler, Messrs. Dugard Bros., Mr. C. Taylor, Messrs. W. Canning & Co., and Messrs. Emery Bros., to all of whom, on the motion of the President, a vote of thanks was unanimously accorded.

The PRESIDENT: I am asked to announce that the Council has approved rules for the guidance of local sections. It is not necessary that they should be read now; they will be printed in the Journal in the usual course. They mostly concern our members who are not resident in London, and who are attached to one or other of the local sections.

I have also to announce that the Council, having appointed a Museum Committee some time ago, has decided to send a circular out shortly to our members, and to other persons having connection with the electrical industry and with electrical science, informing them that we are making —we have, in fact, been making for some years—an historical collection of electrical apparatus. We have already in our possession—unfortunately, for want of room, not displayed as we should like to display it—a large number of interesting specimens of early forms of apparatus, submarine cable, telegraphic apparatus, and appliances of various kinds. Our desire is that that historical collection shall be enlarged and completed, and that we shall be able to secure, before it is too late, specimens which are known to exist in the possession of private persons, and which we fear, if they were lost sight of, might be lost altogether to future generations. We are aware that some of these private possessors of objects of historic interest do not wish to part with them. Our circular will invite the owners of such properties to give us information as to what they are and where they are. But there are no doubt a number of persons owning interesting apparatus of this kind who would be very glad to hand over historic pieces of apparatus if they knew that there was a body such as ours desirous of giving them custody, and taking care of them, and cherishing them, and making use of them as exhibits. We hope very shortly to be able to announce to the Institution the arrangements which are in progress for the due custody and proper exhibition of the things which we already have, and the things which we propose to obtain either on loan or as permanent acquisitions

for our museum. Our Museum Committee has drawn up a circular which will be shortly be issued. We wish to make this announcement to-night in order that it may go into our Journal and into the technical press. We are undertaking this work, we have got it seriously in hand, and we hope during the coming twelve months it may be made a feature of our Institution.

I have received a letter from M. Mascart. He, as you are aware, has been elected a Vice-President of this Institution, and he has addressed to me the following letter, in which he returns thanks for election as Vice-President:—

"PARIS, le 18 mai, 1900.

"Monsieur le President et cher collègue,

"M. le Secretaire de l'Institution of Electrical Engineers vient de m'informer que la Société a bien voulu approuver la proposition du Conseil et confirmer ma nomination comme Vice-President. Je suis très flatté de cette distinction exceptionelle et je vous prie de vouloir bien transmettre mes plus vifs remerciments au Conseil de l'Institution. Je ne me fais pas l'illusion de penser que mes mérites électriques ont suffi pour justifier une telle nomination; je la considère plutôt comme un témoignage d'amitié, où vous avez eu la plus grande part, et j'y suis d'autant plus sensible à ce titre.

"Recevez, mon cher collègue, l'assurance de mes sentiments bien dévoués.

"(Signed) E. MASCART.

"M. Silvanus Thompson."

The SECRETARY read the Annual Report of the Council as follows:—

REPORT OF THE COUNCIL TO THE ANNUAL GENERAL MEETING, MAY 24TH, 1900.

INCORPORATION OF THE NORTHERN SOCIETY OF ELECTRICAL ENGINEERS WITH THE INSTITUTION.

It is with great satisfaction that the Council reports that, in the early part of the period under review, the Institution was approached by the Northern Society of Electrical Engineers with a view to the incorporation of that Society in the Institution, and that as the result of the ensuing conferences and negotiations the incorporation has since been effected in accordance with No. 67 of the Articles of Association. The Council has agreed to remit the Entrance-fees of members of the Northern Society now admitted to membership of the Institution in

consideration of the undertaking of the Society to transfer to the Institution the cash balance standing to the credit of the Society when its Accounts are closed. It is confidently hoped that the union will prove to be of great benefit to the members of each of the societies.

Local Sections.

The Council has also the pleasure of reporting that members and others resident in several centres of the Electrical Industry in the United Kingdom have applied, under Articles numbered 65 and 66 of the new Articles of Association, for the creation of Local Sections of the Institution in their respective districts, and that, in consequence of these petitions, active Local Sections are now in operation in Dublin, Glasgow, the Manchester District, and Newcastle, the Manchester Section having taken the place of the late Northern Society of Electrical Engineers now incorporated in this Institution. A Local Section has also been created in Cape Town. General rules and regulations for the management of Local Sections at home and abroad have been drawn up, and the organisation of the Sections has already assumed a definite form. The Council congratulates the Institution on the initial success of a movement which promises not only to make the Institution more directly useful to its provincial and foreign members, but also to strengthen the Institution itself by rendering it more truly representative of the profession of Electrical Engineering as a whole, and of the interests of the British Electrical Industry at large.

Elections and Transfers.

The Council has the pleasure to report that during the twelvemonth ending May 24th, 1900, acting in accordance with Article 17 of the Articles of Association, it has elected Mr. Joseph Wilson Swan, F.R.S., the last Past-President of the Institution, an Honorary Member.

Notwithstanding the increased severity of the rules relating to the qualifications for membership, and the strictness with which those rules are enforced, the total of the additions to the register by election at Ordinary General Meetings during the same period has been 401. This number is much above the average, and is made up as follows:—25 Members, 88 Associate Members, 3 Foreign Members, 152 Associates, and 133 Students. Adding to these the Honorary Members and the new Members transferred from the Northern Society of Electrical Engineers at the time of incorporation, the total is 471, comprising 1 Honorary Member, 53 Members, 113 Associate Members, 168 Associates, 133 Students, and 3 Foreign Members. Nineteen Candidates have also been approved for ballot to-night.[1]

Six Associate Members, 1 Foreign Member, and 12 Associates have been transferred to the class of Members, whilst 85 Associates have been transferred to the class of Associate Members, and 33 Students to that of Associates.

[1] As these candidates were all duly elected, the numbers representing additions to the register since the Annual General Meeting in 1899 were, at the end of the meeting, as follows: Honorary Member, 1; Members, 57; Associate Members, 116; Associates, 178; Students, 135; and Foreign Members, 3.

Deaths and Resignations.

The Institution has to mourn the loss by death of 1 *Past-President*, Professor David E. Hughes; 9 *Members*, Mark Bevan, T. Buckney, J.D. Doyle, P. B. Elwell, L. Epstein, Frank King, Joseph B. Morgan, Benjamin Smith, and Frederic Wyles; and 8 *Associates*, J. Chapman, H. J. Clipperton, H. T. Constable, M. Cooper, W. B. Edgar, J. J. Tough, W. C. Smythe, and L. G. Willmott.

3 Members, 2 Associate Members, 1 Foreign Member, 23 Associates, and 5 Students have resigned since the date of the last report.

Papers.

In addition to the inaugural address of the President, the following papers have been read and their publication in the Journal ordered :—

At Ordinary General Meetings.

Date.	Title.	Author.
1899.		
Nov. 23.—	"The Cost of Steam Raising"	John Holliday.
"	"Influence of Cheap Fuel on the Cost of Electrical Energy"	R. E. Crompton, Past-President.
Dec. 14.—	"Electrical Time Service"	F. Hope-Jones.
1900.		
Jan. 11.—	"Report of Swiss Visit Committee on the Visit of the Institution to Switzerland."	
" 25.—	"An Electrolytic Centrifugal Process for the Production of Copper Tubes"	S. Cowper-Coles, Member.
Feb. 8.—	"The Standardisation of Electrical Engineering Plant"	R. Percy Sellon, Member.
Mar. 8.—	"On the Applications of Electricity in Medical and Surgical Practice"	H. Lewis Jones, M.D., Associate.
" 22.—	"Storage Battery Problems"	E. J. Wade, Associate.
April 5.—	"The Electrical Equipment of Ships of War"	C. E. Grove, Member.
" 26.—	"The Electrical Transmission of Power"	Prof. G. Forbes, F.R.S., Member.
May 3.—	"The Calculation of Distributing Systems of Electric Traction under British Conditions"	H. M. Sayers, Associate Member.
" 10.—	"A Frictionless Motor Meter"	S. Evershed, Associate Member.
" 17.—	"Alternating-Current Induction Motors"	A. C. Eborall, Associate.

At Meetings of Local Sections.

Date.	Section.	Title.	Author.
1900.			
Feb. 16.—	Glasgow.	"The Problem of Arc Lighting from 250-Volt Supply"	W. B. Sayers, Member.
" 22.—	Dublin.	"Inaugural Address of Chairman"	Prof. G. F. Fitzgerald, Member.
Mar. 23.—	Glasgow.	"Method of Charging for Public Supply of Electricity"	W. W. Lackie, Member.
Apr. 27.—	Glasgow.	"Some Considerations concerning Electric Driving"	H. A. Mavor, Member.
May 15.—	Newcastle.	"Inaugural Address of Chairman"	A. W. Heaviside, Member.

At an Extra-ordinary Meeting in Zürich.

Sept. 6.—	"The Utilisation of the Schaffhausen Water Power"	A. Amsler, Ph.D.

The attendance at the Ordinary General Meetings has been well maintained. By the kind hospitality of the two societies, the meetings from November to April have been held, as in previous years, in the rooms of the Institution of Civil Engineers, and two of those in May in the Rooms of the Society of Arts. The Institution is now, further, indebted to the Institution of Mechanical Engineers for the privilege of using their new premises for two extra meetings in May.

The Publications of the Institution.

With reference to the Journal, the only change of note to be recorded is the alteration in the date of the commencement of the volume, which now runs concurrently with the Session. The first number of the current volume, therefore, contained the proceedings of the meetings in November and December, 1899, instead of those in January, 1900, as would have been the case under the old system.

Recognising the great value of *Science Abstracts* to the Electrical Engineer in placing before him an epitome of most of what is valuable in the current literature of his subject throughout the world, the Council has agreed with the Physical Society for the continuance of the publication under the joint control of the two societies for a further period of at least three years, or of so much longer as may be found mutually agreeable. The scope of the Abstracts has now been enlarged, sections relating to Steam Plant, Oil- and Gas-Engines, Motor Cars, and Medical Electricity having been added, so that the work now appeals to a larger circle of readers than it has done previously, and the growing appreciation in which it is held is indicated by a considerable increase in the proceeds from sales to non-members of the two societies. The number of *Abstracts* published was increased from 1,423 in 1898 to 2,000 in 1899.

The publication of the following papers in the Journal as Original Communications has been ordered :—

In Part 142.—"How Condenser and Choking-Coil Currents Vary with the Shape of the Wave of the Applied E.M.F."	A. Russell, Member.
In Part 144.—"A Two-Phase Rotary Converter and a Note on the Regulation of Rotary Converters"	E. Wilson, Member.
In Part 144.—"The Air-Gap Induction in Continuous-Current Dynamos"	C. C. Hawkins, M.A., Member. R. Wightman, Associate.
In Part 146.—"Note on Air-Gap and Interpolar Induction"	F. W. Carter, M.A., Associate.
In Part 146.—"The Reluctance of the Teeth in a Slotted Armature"	W. B. Hird, B.A., Member.
In Part 146.—"On the Absolute Values of Capacity Measurements"	J. Elton Young, Member.

Annual Premiums.

The Council has awarded the following premiums for papers and communications accepted during the current year. No paper on a telegraphic or telephonic subject having been read, the Fahie Premium

is not awarded. Only those that were in type on the 10th of May were considered eligible, papers accepted for publication after that date being reserved for consideration in awarding the premiums in 1901 :—

The Institution Premium, value £25,

to Mr. C. E. Grove, Member, for his paper on "The Electrical Equipment of Ships of War."

The "Paris Electrical Exhibition Premium," value £10,

to Mr. S. Evershed, Associate Member, for his paper on "A Frictionless Motor Meter."

Two Extra Premiums, value £10 each,

respectively to Professor George Forbes, F.R.S., Member, for his paper "On Distant Electric Power Transmission," and to Mr. H. M. Sayers, Associate Member, for his paper on "The Calculation of Distributing Systems of Electric Traction, under British Conditions."

A Premium, value £5,

to Mr. A. Russell, Member, for an "Original Communication" entitled "How Condenser and Choking-Coil Currents Vary with the Shape of the Wave of the Applied E.M.F."

A Premium, value £5,

to Messrs. C. C. Hawkins, Member, and R. Wightman, Associate, for an "Original Communication" entitled "The Air-Gap Induction in Continuous-Current Dynamos."

The First "Students' Premium," value £10,

to Mr. R. P. Howgrave-Graham, Student, for his paper on "Hertz Waves and Wireless Telegraphy."

The Second "Students' Premium," value £5,

to Mr. C. B. Nixon, Student, for his paper on "Switch Gear for the Generation of the Electric Current."

The Third "Students' Premium," value £5,

to Mr. H. J. Humphreys, Student, for his paper on "Permanent Magnets."

Salomons Scholarship.

The Council has awarded a Salomons Scholarship, value £50, to **Mr. R. P. Howgrave-Graham, of the Technical College, Finsbury.**

Students' Class.

Twelve meetings of the Students' Section have been held during the Session, at ten of which papers were read by Students, the remaining two having been devoted to discussions on electrical subjects.

Visits to the following places were arranged for the Students by your Secretary during the year, and the Council desires to express its thanks to those who, by opening their works for the purposes of these visits, have contributed much to the usefulness of the section:

The Bankside Station of the City of London Electric Lighting Company.

The Davies Street Station of the Westminster Electric Supply Corporation.

The London United Tramways.

The Waterloo and City Railway.

The Works of Messrs. Easton, Anderson, and Goolden.

" " the Electric Welding Company.

" " the Incandescent Electric Lamp Company.

" " India-Rubber, Gutta-Percha and Telegraph Works.

" " the Langdon-Davies Electric Motor Company.

" " Messrs. Siemens Bros. and Company.

Annual Dinner.

The Annual Dinner was held on the 6th of December in the Grand Hall of the Hotel Cecil, the attendance being practically the same as in the previous year.

Annual Conversazione.

The use of the Museum of Natural History was again most generously granted by the Trustees of the British Museum for the Conversazione on June 15th, and the number of guests present was two hundred above the number of those who attended in 1898.

Annual Accounts and Financial Position.

The surplus of income over expenditure at the end of 1899, as shown in the Annual Statement of Accounts, demonstrates that, notwithstanding the contribution in respect of *Science Abstracts* and the increased expenditure on premiums, the financial position of the Institution is thoroughly sound. It should, however, be stated that a somewhat larger proportion than usual of the income for the year resulted from the payment of arrears of subscription, owing to the fact that a phenomenally large number of members was elected at the end of 1898, and that many of these new members did not pay their entrance fees and subscriptions until January, 1899.

The sum of £800 1s. 2d. was invested on account of Life Compositions, leaving on December 31st a balance of £44 9s. 4d., which has since been invested.

The estimated realisable amount of subscriptions outstanding on

the 31st of December, 1899, was £450, and none of this is taken into account in the Balance Sheet now presented. More than £200 of this £450 has since been received.

The Telegraph Jubilee Fund and the Premium Fund have this year, for purposes of the Annual Statement of Accounts, been merged in the General Fund. In the books, however, note is kept of these several amounts.

Building Fund.

The importance of erecting a permanent home for the Institution is recognised by the Council, and they have, accordingly, taken steps to augment the Building Fund. They have transferred from the General Fund the sum of £1,437 10s. 9d., and they have also invited members to make special contributions to the Fund. In response to this appeal £131 11s. 6d. was paid during the two months of 1899 which remained after the date of issue of the circular. These sums, with the interest on capital previously invested on this account and other payments, have raised the amount standing to the credit of the Fund on December 31st, 1899, to £7,044 5s. 11d., as against £5,277 0s. 6d. at the end of 1898.

Wilde Benevolent Fund.

During the Session Mr. Henry Wilde, F.R.S., an Honorary Member of the Institution, generously offered to the Council the sum of £1,500 for the purpose of founding a Wilde Benevolent Fund, to be administered in accordance with the following extract from the Declaration of Trust :—

"The annual income of the trust fund shall, subject as hereinafter provided, be applied in such manner as the said President and Council or Committee of Management shall from time to time think fit for the benefit of members (exclusive of honorary members, associate members, foreign members, associates or students) for the time being of the Institution, but principally though not exclusively for those who by their discoveries, inventions, or writings shall have advanced the profession of electrical engineering, and for the benefit of the families of any such members and of any such late members being deceased, and for the benefit of any persons who may have been such members and paid their subscriptions for five years consecutively at least, and of the families of such persons—subject, however, in all cases to the following regulations :—

"(*a*) The income may in any year be applied wholly for the benefit of one person or class of persons, or may be applied equally or unequally for the benefit of two or more persons or classes of persons.

"(*b*) The total amount applied for the benefit of any one member or late member or his family during one or more years shall not exceed one year's income of the trust fund.

"(c) There shall be no obligation in any year to apply the whole or any part of the income of that year for the benefit of any person or persons. Any income not so applied may, if and so far as permitted by law, be either retained as income to be added to and applied as part of the income of any subsequent year or years, or may be invested and added to the capital of the trust fund."

This trust was gratefully accepted by the Council, and the said sum of £1,500 has been received and invested, although, as it was not made over until the year 1900, it does not appear in the accompanying statement of accounts. It has been decided that, for the present, the fund shall be administered by the Council.

David Hughes Scholarship.

The Council has the further gratification of reporting that the executors of their revered Past-President, the late Professor David E. Hughes, F.R.S., have announced the bequest by him to the Institution of the sum of £2,000, with the object of founding a David Hughes Scholarship, to be awarded under conditions similar to those under which the Salomons Scholarship Fund is administered.

Announcement of the date of the first award will be made when the said amount shall have been received by the Institution.

Local Honorary Secretaries.

The return of Mr. A. P. Trotter to England left a vacancy in the Local Honorary Secretaryship for the Cape and South Africa, and looking to the large number of members in the Transvaal, and to the distance of these members from the previous local headquarters at Cape Town, the Council decided to divide the Secretariat into two sections, namely, the Cape, Natal and Rhodesia, for which district Mr. John Denham, M.I.E.E., has been appointed Local Honorary Secretary, and the Transvaal, to which district Mr. J. Hubert Davies, M.I.E.E., was appointed.

Two new Secretariats have been formed, viz., Italy and Sweden, to which Col. F. Pescetto (Foreign Member) and Mr. John Henrik Hammar (Foreign Member) have been respectively appointed as Local Honorary Secretaries.

The Council has now, by way of experiment, entered into an arrangement for a year with the Société Internationale des Électriciens, under which the Treasurer of each Society undertakes the collection of the subscriptions of members of the other Society resident in his country.

The Council desires to record its cordial thanks to Mr. Trotter for his services as Local Honorary Secretary at the Cape, and especially for his share in the organisation of the Cape Town Local Section of the

Institution, which was being carried on informally and unofficially prior to his return to this country.

Visit of the Institution to Switzerland.

In previous years the Institution has three times held meetings away from London, namely at the Paris Electrical Exhibitions of 1881 and 1889, and at the Edinburgh Electrical Exhibition of 1890, but otherwise no organised visits have been paid to foreign or provincial centres. During the twelvemonth now closing, it was decided to arrange a visit to some of the principal electrical works and installations in Switzerland. With the cordial co-operation of Swiss engineers represented by a reception committee consisting of Col. Huber, Mr. C. E. L. Brown, and Professor W. Wyssling, a programme was arranged and the visit took place on the 1st to the 10th of September. 139 members, and 20 ladies accompanying them, took part in the reunion, and thanks to the efforts of the Reception Committee in Switzerland, and of the Organising Committee at home, and to the untiring labours of our Secretary, Mr. McMillan, the Council is able to congratulate the Institution on the success of the visit.

The Council has arranged for a Joint-Meeting of this Institution with the American Institute of Electrical Engineers in Paris on August 16th of this year, immediately before the opening of the International Electrical Congress; and has also accepted an invitation to visit Berlin in 1901.

Common Seal and Diplomas.

During the period under review the engraving of a Common Seal was completed. The various investments, with the exception of those in respect of the Salomons Scholarship Fund, have now been transferred from the Trustees to the Institution, and are registered under seal. By adopting this course, the Trustees will be put to less inconvenience, and the Institution will suffer no expense, at such times as a change of trustees would otherwise have necessitated the transfer of the stocks from the previous trustees, or the survivors of them, to those newly appointed.

The Council, being also in a position to issue the diplomas for which provision had been made in the new Articles of Association, has notified Members and Associate Members that they are entitled to apply for diplomas. As a result, a large number of these certificates has now been issued. To meet a certain demand for diplomas on vellum instead of on paper, the Council decided that any member could demand such a diploma on payment of one guinea, the surplus of receipts over expenditure on account of vellum diplomas being regarded as a subscription to the Building Fund. Fifty-eight of these vellum diplomas were issued up to the end of 1899, and the subscriptions thus accruing to the Building Fund amounted to £48 5s. 2d.

Electrical Museum.

Recognising the advantage that would accrue to the profession from the formation of a historical collection of electrical apparatus, and the increasing difficulty in making such a collection representative of earlier work, the Council has appointed a Committee, which is now taking active steps to obtain donations or promises of objects or apparatus not now in commercial use, possessing interest in connection with electrical science and its applications.

The Library.

The Report of the Secretary.

I have to report that the accessions to the Library during the year numbered 57; of these nearly all were kindly presented by the authors or publishers.

The presentation of specifications and abridgments of specifications relating to Electricity and Magnetism has been continued by the kindness of H.M. Commissioners of Patents.

A few additions have been made to the periodicals and printed proceedings of other Societies received regularly in the Library. A list is appended.

The number of visitors to the Library during the year has been 555, of whom 50 were non-members.

APPENDIX TO SECRETARY'S REPORT.

TRANSACTIONS, PROCEEDINGS, &c., RECEIVED BY THE INSTITUTION.

ENGLISH.

Asiatic Society of Bengal, Journal and Proceedings.
Cambridge Philosophical Society.
Engineering Association of New South Wales.
Greenwich Magnetical and Meteorological Observations.
Institute of Patent Agents, Transactions.
Institution of Civil Engineers, Proceedings.
Institution of Mechanical Engineers, Proceedings.
Iron and Steel Institute, Proceedings.
King's College Calendar.
Liverpool Engineering Society, Proceedings.
Municipal Electrical Association, Proceedings.
Northern Society of Electrical Engineers, Proceedings.
Physical Society, Proceedings.
Royal Dublin Society, Transactions and Proceedings.
Royal Engineers' Institute, Proceedings.
Royal Institution, Proceedings.

Royal Meteorological Society, Proceedings.
Royal Society, Proceedings.
Royal United Service Institution, Proceedings.
Society of Arts, Journal.
Society of Chemical Industry, Journal.
Society of Engineers, Proceedings.
South African Society of Electrical Engineers, Proceedings.
University College Calendar.

AMERICAN AND CANADIAN.

American Academy of Science and Arts, Proceedings.
American Institute of Electrical Engineers, Transactions.
American Philosophical Society, Proceedings.
Canadian Society of Civil Engineers, Transactions.
Engineers' Club of Philadelphia, Proceedings.
Franklin Institute, Journal.
John Hopkins University, Circulars.
Library Bulletin of Cornell University.
Nova Scotia Institute of Science, Proceedings.
Ordnance Department of the United States, Notes.
Technology Quarterly.
Western Society of Engineers, Journal.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Électro-Technique Montefiore, Bulletin.
Société Belge d'Électriciens, Bulletin.

DANISH.

Den Tekniske Forenings Tidsskrift.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Société Française de Physique, Séances.
Société des Ingénieurs Civils, Mémoires.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Atti.

RUSSIA.

Section Moscovite de la Société Impériale Technique Russe.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION

ENGLISH.

[illegible] Magazine
Electrical Engineer
Electrical Review
Electrician
[illegible]
Engineer
Engineering
[illegible]
[illegible] Magazine
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] Engineer
[illegible]
Philosophical Magazine

AMERICAN.

Electrical Review
Electrical World and Electrical Engineer
[illegible]
[illegible] Telegrapher
[illegible]
Scientific American
Street Railway Journal
Western Electrician

AUSTRIAN.

Zeitschrift für Elektrotechnik

FRENCH.

[illegible]
L'Éclairage Électrique
L'Électricien
L'Industrie Électrique
Journal de Physique
Journal Télégraphique
La Revue Scientifique [illegible]

GERMAN.

Annalen der Physik und Chemie.
Beiblätter zu den Annalen der Physik und Chemie.
Centralblatt für Accumulatoren und Elementenkunde.

Electrotechnischer Anzeiger.
Electrotechnische Zeitschrift.
Zeitschrift für Elektrochemie.
Zeitschrift für Instrumentenkunde.

ITALIAN.

Ellettricità.
Giornale del Genio Civile.
Il Nuovo Cemento.

SPANISH.

La Ingenieria.

The Institution of

STATEMENT OF RECEIPTS AND
ENDING 31st

Dr.

RECEIPTS.

					£	s.	d.
To Annual Subscriptions					4,338	4	0
,, Entrance Fees					743	0	0
,, Advertisements in the Journal					60	0	0
,, Publishing Fund					1	1	0
,, Dividends on Investments, viz.—							
Life Compositions	£136	13	11				
General Fund...	118	14	3				
					255	8	2
,, Interest on Cash on deposit					10	4	10
					5,414	4	6

Electrical Engineers.

EXPENDITURE FOR THE YEAR DECEMBER, 1899.

Cr.

EXPENDITURE.

	£	s.	d.	£	s.	d.
By Salaries				799	13	0
„ Retiring Allowance...				300	0	0
„ Accountants' Fees				10	10	0
„ Shorthand Reporter				57	15	0
„ Attendance, Refreshments, Advance-proofs of Papers, and Petty Expenses connected with Evening Meetings				146	19	4
„ Printing, Illustrating, and Advertising Journal	£835	4	4			
Less cost of copies taken into Stock ...	87	10	0			
				747	14	4
„ General Printing and Stationery (including cost of engraving Diploma Plate and of printing 600 Forms, £41 12s. 0d.)				274	13	4
„ Insurance				10	11	9
„ Office Rent, Electric Light, and Firing				329	8	0
„ General Office Expenses, viz. :—						
Sundries	82	5	3			
Postage of Journals, Notices of Meetings, &c.	391	11	1			
Cost of Illuminated Address to the Queen	7	17	6			
Cost of preparing Common Seal	36	4	0			
Cost of Removal of Stock of Journals from London to Woking	15	5	1			
Cost of Cardboard Cases for Diplomas and of Engrossing Names	14	18	10			
				548	1	9
„ Petty Expenses of Local Honorary Secretaries				2	7	0
„ Bank Charges, viz :—						
Sundries	4	1	10			
Cost of Stamps and Commission on placing Securities under Seal	21	0	7			
				25	2	5
„ Conversazione Expenses (irrespective of Printing and Postage)				245	19	8
„ Premiums (1898–9)...				111	1	1
„ Expenses relating to Institution's Visit to Switzerland ...				30	17	9
„ Contribution to "Science Abstracts"				660	0	0
				4,300	14	5
„ Balance carried to General Fund, being excess of Receipts over Expenditure				1,113	10	1
				£5,414	4	6

LIFE COMPOSI-

Dr.

	£	s.	d.
To Amount (as per last Account)	4,412	10	0
" Life Compositions since received	671	10	0
	£5,084	0	0

"SALOMONS SCHOLARSHIP

	£	s.	d.
To Amount (as per last Account)	2,126	19	3
	£2,126	19	3

TIONS ACCOUNT.

Cr.

						£	s.	d.
By Investments (as per last Account)—								
£400 0 0	New South Wales 4 % Bonds ...	£414	15	0				
318 0 0	Cape of Good Hope 4 % Consolidated Stock	306	0	0				
1,679 19 5	Indian 3½ % Stock	1,776	5	0				
120 0 0	South-Eastern Railway 5 % Debenture Stock	204	16	6				
355 5 10	Canada 3 % Stock	352	13	6				
289 17 4	Midland Railway 2½ % Consolidated Preference Stock ...	274	11	10				
6 0 0	East India Railway Class "C" Annuity	185	1	9				
87 0 0	Great Eastern Railway 4 % Preference Stock	130	15	2				
70 0 0	Great Indian Peninsula Railway 5 % Guaranteed Stock	120	1	6				
143 0 0	Southwark and Vauxhall Water Co. 4 % Debenture Stock ...	207	17	9				
260 0 0	Staines Reservoirs 3 % Guaranteed Debenture Stock	266	11	6				
						£4,239	9	6
Investments Purchased since last Account—								
260 0 0	Staines Reservoirs 3 % Guaranteed Debenture Stock					272	10	9
200 0 0	Glasgow and South-Western Railway 4 % Preference Stock (1894)					276	5	0
175 0 0	Great Eastern Railway 4 % Debenture Stock					251	5	5
						£5,039	10	8
„ Balance uninvested at this date carried to Balance Sheet						44	9	4
						£5,084	0	0

FUND" CAPITAL ACCOUNT.

				£	s.	d.
By Investments, viz.—						
£1,500 New South Wales 3½ % Stock ...	£1,556	5	9			
500 Cape of Good Hope 3½ % Stock ...	570	13	6			
				2,126	19	3
				£2,126	19	3

"SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Balance (as per last Account)	14	4	6
.. Dividends received to date	69	17	7
	£84	2	1

"BUILDING FUND"

				£	s.	d.
To Amount (as per last Account)—						
.. Investments	£5,275	18	5			
.. Dividends uninvested	1	2	1			
				5,277	0	6
.. Dividends received to date				149	18	0
.. Subscriptions received to date				131	11	6
.. Surplus from Vellum Diploma account to date				48	5	2
.. Amount transferred from General Fund				1,437	10	9
				£7,044	5	11

FUND" INCOME ACCOUNT.

Cr.

	£	s.	d.
By Award for 1899, to Mr. H. J. Thomson, of the Central Technical College	50	0	0
„ Balance carried forward to Balance Sheet	34	2	1
	£84	2	1

ACCOUNT.

				£	s.	d.	£	s.	d.
By Investments (as per last Account)—									
£450	0	0	Canada 4 % Reduced Stock ...	£504	0	0			
524	13	0	Canada 3 % Stock	553	10	1			
181	0	0	Great Western Railway 4½ % Debenture Stock	324	17	8			
418	0	0	South-Eastern Railway 3½ % Preference Stock	555	18	9			
370	0	0	London and South-Western Railway Preferred Ordinary Stock ...	510	12	0			
520	0	0	London and South-Western Railway 4 % Consolidated Preference Stock	821	12	0			
190	16	8	India 3½ % Stock	229	9	6			
387	0	0	Great Eastern Railway Consolidated 4 % Preference Stock	575	17	8			
529	12	0	Midland Railway 2½ % Consolidated Perpetual Stock	500	0	0			
350	0	0	Great Indian Peninsula Railway 5 % Guaranteed Stock	600	2	6			
80	0	0	London and South-Western Railway 3½ % Preference Stock	99	18	3			
							£5,275	18	5
„ Investments (purchased since last Account)—									
504	0	0	Staines Reservoir 3 % Guaranteed Debenture Stock	528	5	0			
670	0	0	Glasgow and South Western Railway 4 % Preference Stock (1894) ...	925	11	9			
75	0	0	Great Eastern Railway 4 % Debenture Stock	107	13	7			
15	0	0	South-Eastern Railway 3 % Preference Stock (1899)	15	0	0			
							£1,576	10	4
							£6,852	8	9
„ Balance, being amount uninvested at this date, carried to Balance Sheet							191	17	2
							£7,044	5	11

BALANCE SHEET,

Dr.

LIABILITIES.

		£ s. d.
To Life Compositions—Balance uninvested		44 9 4
„ Subscriptions received in advance—		
On Account of 1900	£54 17 6	
„ 1901	2 11 0	
„ 1902	1 1 0	
„ 1903	0 1 0	
		58 10 6
„ Salomons Scholarship Fund—Balance of Income Account		34 2 1
„ Building Fund—Balance uninvested		191 17 2
„ Sundry Creditors		379 16 0
„ Suspense (Subscriptions) Account, Amounts forwarded in advance for transfer fees, &c.		7 19 0
„ General Fund—Balance as per last Account ...	£4,618 17 2	
Add Premium Fund transferred	213 0 3	
Telegraph Jubilee Fund transferred ...	163 8 0	
Estimated Value of Books presented ...	43 0 0	
Excess of Receipts over Expenditure ...	1,113 10 1	
	6,151 15 6	
Less Amount transferred to Building Fund ...	1,437 10 9	
		4,714 4

WALTER G. McMILLAN,
Secretary.

	£5,430 18 10

We have examined the Books, Vouchers, and Bankers' Certificates as to the Securities of the Institution, and certify that the above Statements of Account and Balance Sheet are correct, and exhibit the true financial condition of the Institution.

WAGSTAFF, BLUNDELL, BIGGS & CO.,
Chartered Accountants,

May 1st, 1900 38, PARLIAMENT STREET, S.W.

31st DECEMBER, 1899.

Cr.

ASSETS.

		£ s. d.
By Investments, "General Fund"—		
£1,418 8 0 Midland Railway 2½% Consolidated Perpetual Preference Stock	£1,200 0 0	
320 0 0 South-Eastern Railway Preferred Ordinary Stock	511 1 0	
918 3 2 India 3½ % Stock	973 17 10	
160 0 0 Great India Peninsula Railway 5% Guaranteed Stock	274 8 9	
		2,959 7 7
" Furniture Account (as per last Balance Sheet)	223 3 6	
Add Additional Book Cases in Library and Office Stool	3 10 0	
" Press and Stand for Common Seal ...	12 10 0	
		239 3 6
" Stock in hand of Institution Journals, Ronald's Catalogues, &c.—		
As per last Balance Sheet	354 9 11	
Cost of Additions in 1899	87 10 0	
	441 19 11	
Less Amount realised during the year ...	132 6 8	
		309 13 3
" Stock in hand of "Cooke's Manuscripts"		18 5 2
" Books, Pictures, &c., other than the Ronald's Library (as per last Balance Sheet)	1,267 10 10	
Add Value of Books and Periodicals since purchased, and Cost of Binding	26 8 9	
Do. Presented	43 0 0	
		1,336 19 7
" Stock of Vellum Diplomas		9 3 2
" Sundry Debtors for Advertisements in the Journal, &c.		36 9 9
" National Telephone Co. Deposit...		0 10 0
" Cash Balances at Bankers'—General Account ...	£469 17 2	
Swiss Visit Account	17 5 7	
Petty Cash Account	34 4 1	
		521 6 10
		£5,430 18 10

F. C. DANVERS }
E. GARCKE } *Honorary Auditors.*

The PRESIDENT: Gentlemen, in moving the adoption of the report of the Council I need not, I think, add anything by way of a lengthy contribution to the information that has now been laid before you officially by the Council; I will only very briefly comment on what seem to me to be the two most important things that have happened during the year. The first, and by far the most important, is the growth of the organisation of the Institution in its local sections. That which we have been contemplating for several years, that for which we made express provision in our new articles of association, has become during the session which concludes to-night an accomplished fact. We have now spread our roots in five different centres—in Dublin, Glasgow, Manchester, Newcastle, and Capetown, with a local organisation in each. I need hardly tell you that, in my view at any rate, this is by far the most important thing that has happened for a good many years. We hope to see a few more such local organisations added as time goes on; indeed it is perhaps revealing no secret to tell you that there are active negotiations on foot for another local centre in England which probably may be organised in the present year, though not of course during the present session. The Council and the members of the Institution may congratulate one another most heartily that these local sections have been formed, that they have got to work, that they are already sending in papers to be printed in our Journal, and that the local interest which is being aroused in the work of the Institution is already bringing in members and consolidating our efforts in a most gratifying way.

The other matter that I want to allude to is the growth of our Building and Benevolent Funds. It is no small matter, I think, that the Institution has been able during the current session to add nearly £1,800 to the Building Fund, partly by its savings during the previous session and during part of the current session, and partly by special subscriptions collected for the purpose. You will have noticed in the reading of the report how the actual sum at our disposal as a Building Fund has grown, since the date of our last annual report, from £5,277 0s. 6d. to £7,044 5s. 11d. Now there is a considerable difference between those two sums, for it represents an increase in that nucleus of a Building Fund quite substantial enough now to justify the Council in

stepping forward to that first and most necessary preliminary, viz., the acquisition of a site. You know that our Council has been during the past session actively on the look-out for a suitable site. A suitable freehold site of such a size as we shall require will certainly cost us more than £7,000, but £7,000 is quite enough to secure that site, and once we have our site secured we can very easily, and I have no doubt successfully, appeal to the membership generally for the necessary funds to complete the purchase and to go on with the beginning of our building. There are ways and means, when we have a nucleus, of at any rate adding to that nucleus *pro tem.*, and raising money on mortgage, and therefore the fact that we have a nucleus of £7,000 has brought us, during the present year, literally within sight of the possibility of creating for ourselves that permanent home which I hope it is the desire of every one to see in the possession of the Institution. The Benevolent Fund appeals, of course, to a different sentiment, the sentiment of desiring to provide against any misfortune occurring to our members, and it has largely grown, and grown in two directions. Our old Benevolent Fund, which is administered not directly by the Council, but by a Committee on which our Council is officially and largely represented, has grown, particularly during the last month or two, thanks to the activity in particular of one member of the Committee, though not only of him, who has busied himself in this most laudable effort to increase the subscriptions to the Benevolent Fund. We have, in addition, the Benevolent Fund which bears the name of our Honorary Member, Mr. Henry Wilde, and we are grateful for that magnificent contribution which he has made to our resources in the founding of the Wilde Benevolent Fund.

These are very distinct points of progress on which we may congratulate ourselves and the membership at large. I have done my duty in drawing your attention to them, and I beg to move "That the Report of the Council, as just read, be received and adopted, and that it be printed in the Journal of the Proceedings of the Institution."

Mr. J. E. KINGSBURY: As a member of the Institution, I feel it is quite unnecessary for me to add any remarks to those of the President, except to congratulate the Council on the facts which have been disclosed. I beg to second the motion.

The PRESIDENT: The Report is now open for discussion.

Mr. H. FENTUM PHILLIPS: I have great pleasure in supporting the adoption of the Report. I am particularly glad to see the Council is again going forward with the nucleus of a Building Fund. Of course we are a powerful, a large and influential body, but at the same time we can only hold our meetings by the courtesy principally of the Institution of Civil Engineers and the Society of Arts, and on two occasions this session to the Institution of Mechanical Engineers. I am sure that all our members will feel with me that when all is said and done, we to a certain extent have the feeling that there is no place like home. I think the sooner we can get a home of our own the greater it will be not only to our credit but to our convenience. I was also very pleased to see that there is some suggestion of forming a Museum. I think that will be a very interesting thing, not perhaps just at present, but in years to come.

Mr. W. MCGREGOR: I should like to congratulate our Institution on the local centres, the creation of which is a very important step, that must prove of great use to people who are unable to come to London. I am here to-night after twenty-five years of membership. I have not had an opportunity once of attending any of the meetings in London owing to absence in India, and I was determined I would come to-night to support the formation of local centres. I think you will find they will be a very great success indeed. I have tried to move in the matter at Bournemouth in my own small way. I congratulate the Institution on having made such a good start, and I hope we shall have a large increase of these local centres.

Mr. J. W. SWAN: I am very glad to have been present to-night to hear the reading of the Report, the best Report ever issued on the occasion of any of the Annual Meetings of the Institution, showing progress in every department, in the membership, in the revenue, in the institution of local centres and in the number and quality of papers. In every respect there is very strong evidence of good progress. I congratulate the Council and members and the President on such a successful year. I was taken by surprise when I found my own name occurring in the Report. I knew that the Council had done me the honour to elect me as an Honorary Member, but it never occurred to me that this would be mentioned. I cannot quite pass over the very kind way in which the announcement was received without acknowledging the pleasure I have in this mark of your appreciation. If there is a drawback at all, perhaps it is in the reminder it conveys of the fact that one is growing old. And yet I trust that I am not too old to be permitted the hope of being able yet to do some useful work towards the further advancement of electrical engineering.

I wish to give expression to the pleasure I have felt in hearing such an admirable report read, and I hope it is the forerunner of many other reports having the same characteristic of continual progress.

The resolution for the adoption of the Report was then put, and was carried *nem. con.*

The PRESIDENT: I beg to move that the Statement of Accounts and Balance Sheet, of which copies were sent to the members with the notice convening the annual general meeting, be taken as read.

The motion was then put and agreed to.

The PRESIDENT: I beg to move "That the Statement of Accounts and Balance Sheet for the year ending December 31st, 1899, as presented, be received and adopted."

Mr. HIRST: I have much pleasure in seconding this resolution.

Mr. J. S. RAWORTH: I should like to say a word or two on the Balance-sheet, not from the point of view of criticism, but rather as respecting the few words which have dropped into my ears from the various members of the Institution who seem to think that I take a paternal interest in the Balance-sheet.

In the first place I have to report that everybody that I have spoken to is full of admiration for the Finance Committee and for the Secretary and Treasurer for the manner in which they have presented this Balance-sheet. It is, I think, the handsomest and most lucid Balance-sheet that we have ever had in our hands, and it has this advantage, that you have not to pore over it for hours or even minutes. I think five minutes is sufficient to get a clear understanding of the position of the Institution. One of the most charming features of the Balance-sheet is that we see that the Building Fund is of its own accord growing at the rate of £150 a year. That, added to what we get from the vanity of the members for the vellum certificates will, I have no doubt, gradually provide us with a home.

There are one or two points which have been brought to my notice which I think might be mentioned for the benefit of the members. Perhaps somebody may be able to give information on those points on which I cannot supply it. First of all, the postage of Journals and notices of meetings amount to £391 11s. 1d., and some people think that a very large sum of money for us to pay over to the Postmaster-General. I can assure members who have any feeling of that kind that the subject has already taken a considerable amount of the time of the Committees concerned, and they have come to the conclusion that however desirable it may be to reduce our expense in that direction, it is so far incapable of reduction. The Secretary himself I know has gone to very great personal effort in trying to devise cheaper methods of distributing the printed matter of the Institution. It is because the volumes are growing fatter and heavier every year that this item of expense in distributing them naturally increases. Another point is the cost of preparing the Common Seal, £36 4s. At first sight it looks a rather excessive amount for preparing the Common Seal; but this is not a common Seal—it is only a Common Seal in name—and if you had any idea how much time and talent the Council has brought to bear on its preparation, I am sure you would sympathise with them and condone the expense. We have tried every conceivable idea, and finally we settled upon having a likeness of Faraday. It took us a great deal of trouble to get a good likeness, but I think the Institution generally is satisfied with the result.

The resolution for the adoption of the Accounts was then put, an was carried *nem. con.*

Professor J. PERRY: We have all heard about a new buildin which for so long has been a sort of pious wish, but which is no coming well into view. We have heard of meetings at Paris and Edinburgh and in Switzerland, and we have had meetings here and the Institution of Mechanical Engineers, but I think you must agree with me that there is one building to which we really do feel attachment, the attachment which is associated with the houses we hav known in our youth, and that is the building of the Institution of Civ Engineers. It is a very beautiful building, and they have given us th easy use of it for a great length of time. The Institution of Civ Engineers might be almost called the parent bird of this Society. don't think it can be regarded as the bird that laid the egg, but suppose to some extent it may be looked upon as having hatched it, and possibly it is sometimes a little astonished at the experiments that w occasionally make. The fact is we are a duck, and a hen has hatched us. I think we must all feel that the Institution of Civil Engineers has been exceedingly civil to us from the very beginning. I therefore beg to propose, "That the members of this Institution hereby express their sincere and hearty thanks to the President, Council, and Members of the Institution of Civil Engineers for their kindness and liberality in permitting the meetings of this Institution to be held in their Lecture-hall."

Mr. McGREGOR: I have very great pleasure in seconding this resolution. We must all feel we have been in a home, what is called among boarding-house-keepers a "home from home." It has been a home to us hitherto, and I believe we feel that we are under a very great obligation to the Institution of Civil Engineers for allowing us the use of those rooms in our early days, and up to the present time.

A member is very warm on the subject of our future home, but until we get that future home I am sure we cannot do better than behave ourselves as good children in the home that we possess at the present moment. Therefore I have great pleasure in seconding the resolution.

The resolution was carried unanimously.

Mr. J. GAVEY: Pending the acquisition of that home of which we have heard such cheerful accounts to-night, we are indebted not only to the parent Society for its hospitality, but to certain other Societies who have been good enough to lend us their houses from time to time. There is perhaps one advantage attendant on this period of wandering in the desert—there are always compensations in all walks of life,—namely that we may hope that when we do acquire our own home we may have gathered certain hints from those we have made use of from time to time as to the best sort of home to provide. We may perhaps scarcely hope to be surrounded with such artistic embellishments as we have here, but let us hope we may combine a little Art, a great deal of Science, and a good deal of the solid comfort which will aid us in the consideration of the abstruse subjects which come before us from time to time. It is not necessary to dwell at length on this point, but I will

simply propose "That the members of this Institution hereby express their hearty thanks to the President, Council, and Members of the Institution of Mechanical Engineers, and to those of the Society of Arts, for their kindness in allowing meetings of this Institution in May to be held in their respective rooms."

Mr. H. W. WILKINSON: I have very great pleasure in seconding that resolution.

The PRESIDENT: In putting this motion to you, I wish to take my privilege of saying a word. Possibly many of you do not know to what a large extent this actual room is historical in the development of electricity. It was in this actual room in the year 1825 that William Sturgeon showed the first soft-iron electro-magnet; it was in this room in 1845 that a lecture was given by Mr. Francis Whishaw on the subject of gutta-percha. That lecture was listened to by the young William Siemens, who forthwith sent a specimen to his brother, Dr. Werner Siemens, in the expectation that he would find in it the material for which he was then seeking for the insulation of submarine cables. I repeat, this room is historical, and I think that is all the more reason we should give more cordial thanks to the Society of Arts.

The resolution was then put, and carried unanimously.

Mr. J. W. SWAN: I wish to move "That the thanks of the Institution be given to the Local Honorary Secretaries and Treasurers for their services during the past year." I am sure you all feel, as I do, that they are fully entitled to our best thanks: they do us an immense service.

Mr. R. S. ERSKINE: I have much pleasure in seconding that. I understand from the Report that one of the people we have to thank is Mr. Trotter. I understand he was Local Honorary Secretary at the Cape, and I have great pleasure in seconding the motion, as Mr. Trotter took such an active part in founding the local centre there, and so leaving a record of his services.

The PRESIDENT: These are the Local Secretaries and Treasurers not of our five local branches, but the Honorary Secretaries wherever we have them, in all parts of the world—in India, Canada, Australia, and in various countries in Europe, including those who have been made Local Honorary Secretaries in the past year in Italy and Sweden. It is a somewhat comprehensive vote, but the Institution owes a great deal to the energy and devotion of these gentlemen, whose services enable us to keep in touch with our scattered membership through the whole world.

The resolution was then put, and carried unanimously.

Mr. J. S. RAWORTH: I beg to propose "That the thanks of this Institution be accorded to Professor Ayrton for his kind services as Honorary Treasurer during the past twelvemonth." You know Professor Ayrton in his character of Professor better than I can tell you. But you do not know him in his capacity of Treasurer. I do; and I can assure you his services are not fully described when they are called "kind." They are absolutely admirable. He is built on the principle of the old pot savings banks—you can get the money in easily enough,

but you can never get it out again. I am sure this Institution is bound to have Professor Ayrton as Treasurer as long as he lives, because you will never get money out of him, however much you try, except by grinding him up with a pestle and mortar. Another thing is that he has done the best he can to increase the interest accruing to this Institution from the investment of the funds. He has had this very strongly on his mind, and he does not intend this Institution to go without a good return for want of trying to get interest on the money that is put out.

Mr. H. M. SAYERS: I have much pleasure in seconding this motion. I think we must all agree that when a man with the many engagements and business interests of Professor Ayrton takes upon himself the responsible position that he has done, no mere words can fully repay the debt we owe him for the work which he does in our interests.

The resolution was carried unanimously.

Mr. A. J. LAWSON: I beg to move "That the thanks of this Institution be given to Mr. F. C. Danvers and Mr. E. Garcke for their kind services as Honorary Auditors during the past year." You may rely upon it that as auditors what they do they do well.

Mr. J. RENNIE: I have much pleasure in seconding the resolution.

The resolution was carried unanimously.

Mr. A. A. C. SWINTON: I have a resolution to propose which I am sure will commend itself to every one. I do not know that the members of this Institution are more litigious than other people, but every one who employs lawyers is aware that usually they are very expensive. I have recently been engaged in a case in which several lawyers were employed, and I calculated roughly they were costing at the rate of about £5 a minute. I am now appalled at the idea of the bill which will shortly be delivered. We have the great benefit in this Institution that we have an honorary lawyer who does all our work for nothing. I think I ought to say that he has a great deal of work to do. Last year he had much to do in connection with our new Articles of Association. This year he has given us a great deal of his time in connection with the rules for the new Local Sections of which we have heard the great importance, and also in connection with the arrangements for the Wilde Trust. I have therefore great pleasure in moving the following resolution, "That the best thanks of the Institution be tendered to Messrs. Wilson, Bristows, and Carpmael for their kind services as Honorary Solicitors during the past year."

Mr. W. M. MORDEY: It is more or less natural, I suppose, for electrical engineers to work for the good of this Institution, but we have not the same sort of claim on others to do so. I think that ought to make us all the more grateful to our Honorary Solicitors, especially as, so far as I know, they are not getting any part of the £5 a minute which Mr. Swinton has mentioned. The proposer of the motion is quite right in saying that the duties carried out by the Solicitors are not merely formal. They have a great deal to do, and you will quite understand that the growth of the Institution, the number of fields in which activity is being spread, and the important questions of building sites and administration of funds and so on, make it very necessary

we should be exceedingly well advised, as indeed we are. I hope we shall pass a hearty vote of thanks.

The resolution was carried unanimously.

The PRESIDENT: I am only sorry Mr. Bristow has found it necessary to leave the meeting to keep another appointment—he was here only a few moments ago. I should have liked him to be present to hear how the members appreciate the really arduous services which he has discharged so excellently for us, and entirely gratuitously.

The next business is to announce the result of the election of the Council and Officers for the year 1900-1901. The Articles of Association provide that the names shall be read, as they were a month ago, and circulated to all the members, giving the members an opportunity of making any alternative proposals. It so happens that in the present year no alternative proposal has been made by any member for any office, and therefore the whole of the members proposed in their various capacities have been elected, as I have already mentioned in the case of one of the Vice-Presidents, Mr. Mascart.

President.

Professor J. PERRY, F.R.S.

Vice-Presidents.

W. E. LANGDON.
JAMES SWINBURNE.
R. K. GRAY.
E. MASCART.

Members of Council.

Major P. CARDEW, R.E.
H. H. CUNYNGHAME, C.B.
H. EDMUNDS.
S. Z. DE FERRANTI.
JOHN GAVEY.
ROBERT HAMMOND.
HUGO HIRST.
J. E. KINGSBURY.
A. J. LAWSON.
P. V. LUKE, C.I.E.
W. M. MORDEY.
R. P. SELLON.
C. P. SPARKS.
A. A. CAMPBELL SWINTON.
A. P. TROTTER.

Associate Members of Council.

W. R. COOPER, M.A., B.Sc.
S. EVERSHED.
R. W. WALLACE, Q.C.

Honorary Auditors.

FREDERICK C. DANVERS.
E. GARCKE.

Honorary Treasurer.

Professor W. E. AYRTON, F.R.S., Past-President.

Honorary Solicitors.

Messrs. WILSON, BRISTOWS, & CARPMAEL.

I omitted to make one announcement at the time announcements were being made. It is this, that the hours during which the Library of the *Institution is open* will be altered. They have been open till

8 o'clock at night on certain days of the week, and closed on certain others—on Thursday afternoon and evening. On considering the question the Council has decided that henceforth the Library shall be open every day except Saturdays till 6.30, and on Saturdays until 2 o'clock.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members :

Charles Henry Davis.
William Martin Haddow.
Henry Heileman Wait.
Louis James Benard Wall.

Associate Members :

William James Proctor.
Norman Rheam.
Arthur Hugh Seabrook.

Associates :

Herbert Bingham.
Arthur Reginald Cooper.
Ivon Molesworth de Havilland.
Frank Hope-Jones.
John Watson Jack.
Frederick Charles Pay.
David Robertson.
Albert Edward Short.
Alexander Thomas Stewart.
William Francis Whittaker.

Students :

Francis Percy Seager.
Frank Herbert Wigner.

The PRESIDENT : This concludes the business of this Annual Meeting and of the session. We hope to meet again, under the Presidency of Professor John Perry, in the autumn.

GLASGOW LOCAL SECTION.

Paper read at Meeting of Section, April 27th, 1900.

SOME CONSIDERATIONS CONCERNING ELECTRIC DRIVING.

By H. A. MAVOR, Member.

THIS communication has been hurriedly prepared to fill the gap caused by the falling through of the proposed arrangement to have a Presidential Address from Lord Kelvin on this evening. The object of the paper is to suggest points for discussion in connection with the use of small motors.

The institution of public supply stations for the distribution of power is now well begun in this country, and is likely to show very important developments in the immediate future.

It is not necessary to prejudge the case now being considered by a Committee of the House of Commons to determine whether or not the public supply of power ought to be in the hands of the local or municipal authorities or in the hands of private companies. In either case the results as regards the practical requirements for the supply of motors are likely to be qualitatively if not quantitatively similar.

The chief determining factor in the quantity of motors to be required will be the price for the supply of electrical energy.

It seems probable that the price to be aimed at in the immediate future will be about 1d. per unit for a 500-volt supply on three-wire system. It is not probable that this price will be seriously reduced in such a time as need be considered for our present purpose.

It is well known that large users of power can produce electric energy for their own purposes at or about this figure, and it is very unlikely that they would in any case draw upon the public supply, and therefore the demand is likely to come rather from users of small powers or of large powers in such an intermittent manner as to preclude economical production.

The fixing of a standard voltage of 500 and continuous

current for public supply must necessarily tend to standardise private supply on the same lines, not only because of the convenience of interchange of sources of supply by the user, but because of the preference by the manufacturer to supply a standard article. It may be assumed that the probable range of sizes of motors required for connection to public supply will be normally from about ½ H.P. to about 20 H.P. each. The lower limit is certainly far above the power required for many industrial operations, but the manufacture of motors below ½ H.P. for use, even on 250-volt circuit, is not likely to be satisfactory, for two reasons:

First, because of the high initial cost in proportion to the effective power; and

Secondly, because of the very inefficient working of the smaller sizes.

In cases, therefore, where the individual units are smaller than ½ H.P., as, for example, sewing machines, they will probably be grouped so as to utilise the larger sizes of motors.

From the users' point of view efficiency is usually a matter of secondary consideration until the experience of comparative bills of cost induces a more intelligent inquiry into the relative values of the motors. In the first instance, the capital cost of the motor is too often allowed to be the sole determining factor in choosing it. The cost of the ½ H.P. motor may be taken at about £15, and the cost of running it nine hours per day for a year at 1d. per unit would be about £5, so that the calculation of the value of improved efficiency is a simple one; *i.e.*, a saving of 10 per cent. on efficiency on the motor would amount to 10s. per annum. The charge for interest and depreciation of £15 being taken at 30s., an increase of one-third in the price of the motor would be justified if it gave 10 per cent. better efficiency. This would approximately increase the size of the motor by about twice, and the argument is therefore a strong one in favour of spending money on material for the purpose of gaining increased efficiency on motors of this size.

The smaller the machine is, the greater the handicap under which it works.

The use of smaller machines is attended with further

disadvantages in the direction of frequent necessity for and difficulty in carrying out repairs.

Looking at the matter now from the manufacturers' point of view, let us consider how the probable demand for motors can best be met.

Motors of 5 to 20 H.P. present no difficulty. They can be economically designed and made at a reasonable cost.

The smaller motors, on the other hand, if they are to be efficient working machines, present many difficulties. The cost of material for the smaller machines of normal design as regards their magnetic and electric features bears a very high proportion to the total value of the machine, and the amount of labour to be expended upon these materials is made up of so many small items, that it is extremely difficult to effect any material saving in cost. These facts apply more especially to the manufacture of small shunt-wound machines for high voltage. The manufacturer would therefore probably prefer to supply for the small sizes series-wound motors, and they may fairly plead the several advantages from the users' point of view to weigh in the consideration.

A series-wound motor is more easily started with the load.

The maximum current required to give the starting torque is usually less in the series motor than in the shunt motor, and therefore the starting resistance need not necessarily be so large ; the resistance of the series winding of the motor supplements the starting resistance.

As there is a much smaller number of turns of wire on the series motor, the inductive effects on making and breaking the current are much less likely to cause damage to the motor and to the starting switch.

Series motors can be designed to give a comparatively small variation of speed within ordinary working limits if they are properly applied to the work, and if care be taken that the machine is not working at an improper speed, either above or below its most efficient range, then the efficiency need not be worse and may be better than that of a shunt-wound machine.

The use of a series-wound motor for a very large proportion of industrial operations does not appear to present any serious difficulty. It is perhaps not very generally recognised that the working efficiency of nearly all manufacturing machines is extremely low, so that the variation of load produced by change in the amount of work done by the machine is much less important than would at first sight be anticipated; for example, a bank of sewing machines running light, *i.e.*, without stitching, absorbs very nearly as much power as when the machines are stitching. Printing machines, if they are in motion at all, absorb about the same power, whether they are printing or not. Tools used in engineering manufacture are not more efficient than those used in other industries. The insertion of the tool into the work in a turning-lathe produces a surprisingly small variation in the current required to drive the lathe. The same is true to an even greater extent in the case of planing machines, and to a less extent in the case of milling machines.

It is easy to design a series motor so as to give a variation of power which is amply sufficient to cover the fluctuations arising from variations in work done by the machine, and to maintain the speed within a range of variation similar to that which occurs in all belt-driven machinery; and this can be done with a very slight variation in the efficiency of the motor. The necessarily high resistance of motors of the size under consideration, and their relatively low efficiency even under the best conditions, puts practically out of account any risk of damage from the motor running away when lightly loaded. Many starting switches are now in use with magnetic devices for cutting off the supply when the current falls below a desired minimum or rises above a desired maximum, and there need be no fear of damage on this score.

The insurance companies are beginning to take an interest in the subject of electric driving, and care must be taken by engineers and all concerned that they are not allowed to impose absurd restrictions, such as have so much hindered the proper development of electric wiring arrangements. In Glasgow so far there is not much of which to complain, but already proposals have been made by insurance companies which tend to injuriously affect the

convenience and efficiency of electric motor arrangements. The best way to deal with the companies in such matters is, while treating them confidentially in the way of explaining what are the real dangers and how they ought to be avoided, and giving them every encouragement to insist upon good workmanship, to be perfectly firm in refusing to adopt any absurd measures, such, for example, as placing motors on insulated non-combustible bases.

The indications are that the enclosed motor is likely to be largely adopted in preference to the open-type machine; and on the whole this is quite a defensible preference, but it must not be forgotten that the enclosed motor is a less efficient machine than the open motor.

The starting switch is a much more probable source of danger, and in fact much yet remains to be done from the designers' and manufacturers' standpoint to make the starting switch even for small motors a thoroughly satisfactory article. The liquid switches largely employed in connection with some of the electric lighting stations seem on the whole to give satisfactory results, but the arrangement is more cumbrous and expensive than it ought to be, and is too liable to get out of repair from corrosion, or to become ineffective from evaporation of the liquid. The American types of wire starting switches which have been largely imported into this country are not satisfactory, and in fact the problem is still an open and unsolved one.

The enlightened policy now being followed by the Glasgow Corporation electrical engineer is likely to result in a very large demand for motors, and it would appear that there is here a more interesting and productive field of enterprise for the electrical engineer, as distinguished from the wireman, whose reputation is as good, and his character no better than it ought to be.

There are a thousand interesting problems awaiting solution at the hands of electrical engineers for the application of electric power to all departments of industry, and there is now no lack of interest on the part of the public, so that an intelligent and skilful application to the problem will certainly result in profit to those engineers who have the ability to solve it.

[redacted]

DESCRIPTION OF CURVES.

These curves, the object of which is to compare the performance of the same motor when the magnets are (1) series wound, and (2) shunt wound, are calculated from a small motor, the maximum load of which would be about 8 amperes. It has been chosen with fairly high resistance both in the magnets and in the armature, as the results of these resistances on the curves are then more easily visible. In either case the abcissæ are amperes and the curve is carried to the maximum current which the motor resistance would let through when the armature is standing still.

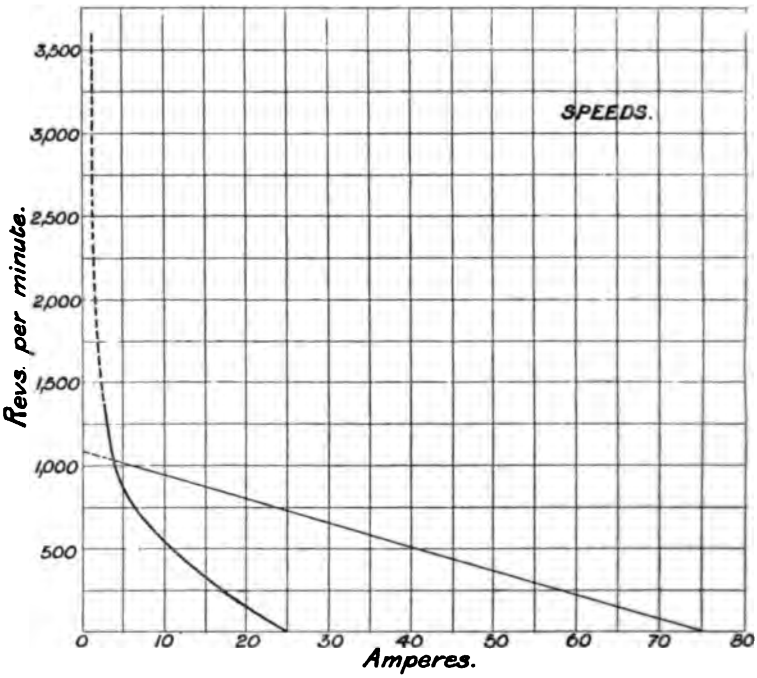


FIG. 1.

Curve No. 1 is plotted with revolutions per minute as ordinates.
„ No. 2 with effective watts „ „ „
„ No. 3 with C^2R losses „ „ „
„ No. 4 the torque „ „ „
„ No. 5 the efficiencies „ „ „

In each case the light curve indicates the performance of the motor with shunt winding, the heavy curve with series winding.

Curves No. 1 and 2 are the more important; No. 3 is only used in order

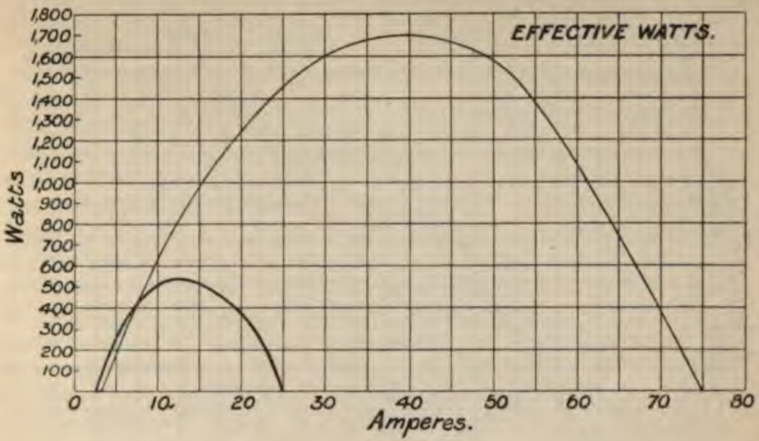

EFFECTIVE WATTS.
Watts
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
10
20
30
40
50
60
70
80
Amperes.

FIG. 2.

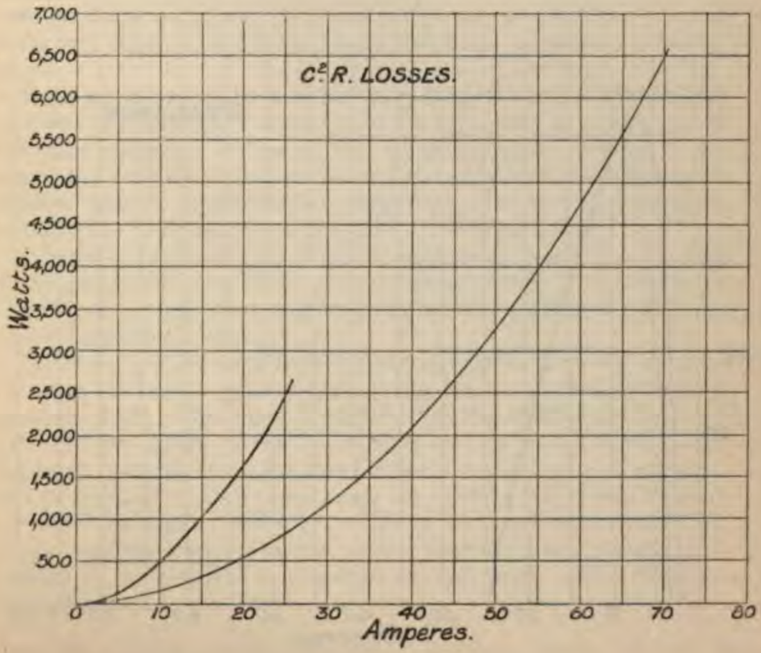

C².R. LOSSES.
Watts.
7,000
6,500
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
10
20
30
40
50
60
70
80
Amperes.

FIG. 3.

[redacted]

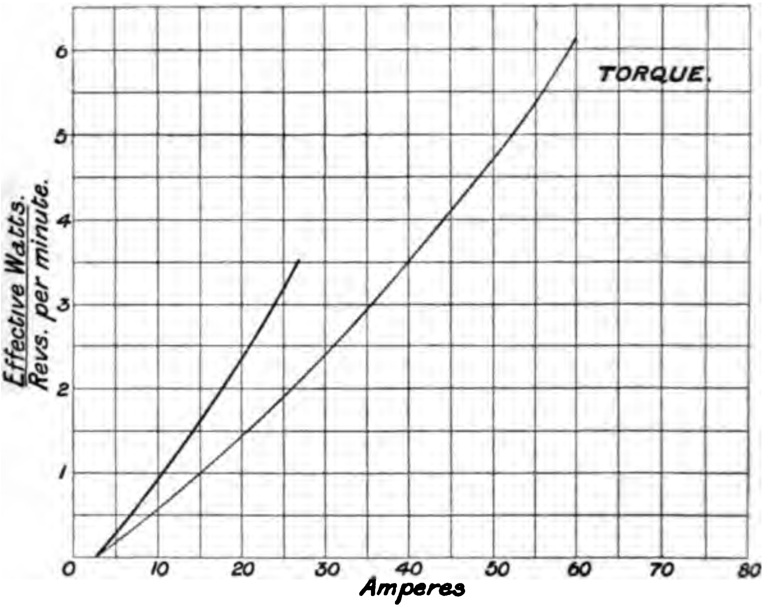


FIG 4.

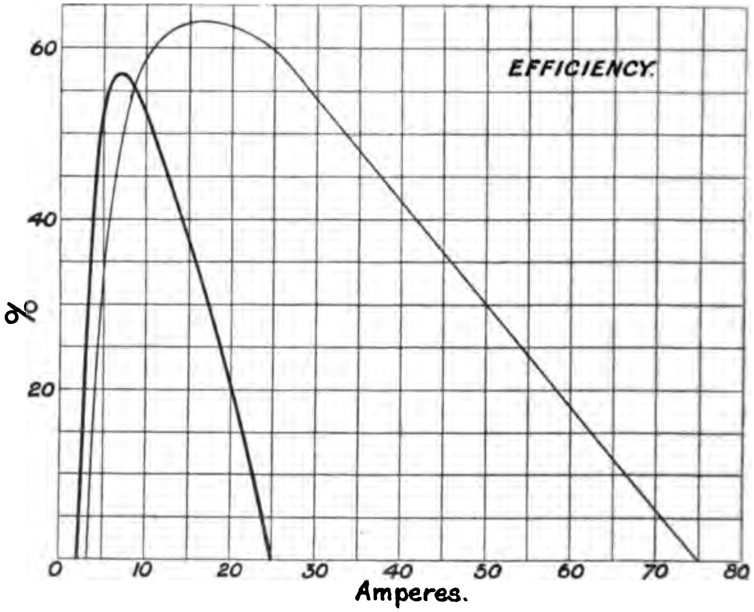


FIG. 5.

to obtain 1 and 2, whilst 4 and 5 are derived immediately from 1 and 2 and not directly from the data of the motor.

Taking No. 1 first, the interpretation of the curve is as follows :—

If the armature is held with a torque sufficient to prevent its rotating, the current will be about 72 amperes in the case of the shunt-wound motor, about 25 in the case of the series-wound motor. This difference is of course due to the comparatively large resistance of the series coils. As the torque is decreased, the current is reduced and the speeds increase as shown by the curves. When we get to a current of about 3·2 amperes for the shunt and 2·8 for the series, the whole of the watts are employed in driving the motor, which, as shown on curve No. 2, has no effective watts, *i.e.*, is unable to do external work. It should be noted that although the curves are continued (dotted) below this point, showing the speeds at which the motor would run if a less current than 2·8 and 3·2 respectively were allowed to pass, it is impossible in this particular motor and under the conditions in which the curves are drawn, viz., a constant impressed E.M.F., to obtain any smaller current than those indicated ; the only way to do this would be to reduce the E.M.F. at the terminals of the motor, which is contrary to the conditions under which the curves are drawn, or to apply a negative torque, *i.e.*, run the machine as a generator.

Curves No. 2 explain themselves. They are obtained by subtracting from the watts impressed on the motor (1) the C^2R losses as shown on curve No. 3 ; (2) in the case of the shunt motor, a constant quantity of 160 watts for shunt excitation ; and (3) in both cases an allowance for core losses and friction, which has been taken as proportional to the speed.

In curve No. 3 the light curve indicates the C^2R losses in the armature ; the losses in the armature when the motor is wound as series will, of course, be practically the same, only differing slightly because in the case of the shunt-wound motor the shunt current, in this case about 1·6 amperes, does not pass through the armature. The heavy curve shows the combined losses in the shunt and in the series windings.

Curve No. 4 is simply the effective watts from curve No. 2 divided by the speed from curve No. 1. The ordinates shown on the curve are a ratio, and are not plotted to any special unit. This, of course, is merely a question of scale.

Curve No. 5 is the ratio between effective watts as shown on curve No. 2 and the total impressed watts. It is interesting to note that the efficiency of the series motor is higher than the shunt at low currents when the C^2R losses in the series are small, the losses in the shunt remaining constant throughout the range. As the current increases, the C^2R losses in the series soon reach the value of this constant shunt loss and then rapidly exceed it. This is the cause of the efficiency curves and the effective watts curve dropping away rapidly and finishing at 25 amperes in the case of the series, whilst they are prolonged to 72 in the case of the shunt.

Mr. W. B. Hird described the curves which Mr. Mavor referred to *in the course of his paper.*

Mr. Chames

Mr. W. A. CHAMES said that the thanks of the meeting were due to Mr. Mavor for the paper, which, although very short, contained matter of the greatest interest. He did not quite follow Mr. Mavor in some of the cases where series- appeared better than shunt-motors, and would like to know if the curves were plotted from experimental data or from calculated results. He had always thought that a series-motor was the thing for sudden bursts of load, but from the diagrams it seemed that shunt-motors would be far better in such cases. He mentioned that to him personally a more interesting point was the method of switching the motor on and off, and, although there were many different types of gear for this purpose, some of them seemed needlessly complicated and no better suited to the purpose than a much simpler arrangement. An arrangement which he used for a long time he sketched on the board, and he said that it was both simple and very satisfactory. He emphasised the importance of getting the shunt fully excited before the armature circuit was fully closed, and, as would be seen from the sketch, this switch met this requirement. He also pointed out that an automatic shut-off switch was essential for shunt-motors, as machines were often placed in positions where the supply might from some cause be stopped temporarily, and if there were no shut-off switch the consequences might be serious when the supply recommenced.

Professor Gray.

Professor A. GRAY stated that it was a most interesting paper and he had learned much from listening to it, but before discussing it or making any remarks he would have liked to have an opportunity of carefully reading it through. He thought the paper a good illustration of how interesting and important facts could be condensed into diagrams, and he had studied them with the greatest interest.

Mr. Coates.

Mr. COATES pointed out that in some machines there was a great difference between no-load and full-load, as, for instance, in hay-cutting and oat-crushing machines.

Professor Watkinson.

Professor W. H. WATKINSON thought that series-motors were only suitable when the load was constant, as the speed was not so easily regulated. He referred to the difficulty in getting speed variation, and pointed out that in many industrial operations variable speed with constant torque would be necessary, yet so far there seemed no effective method of obtaining that in a satisfactory manner, although he understood that Mr. Ferranti had recently devised a motor to overcome this difficulty, and he should very much like to have particulars of it.

Mr. Stewart.

Mr. A. STEWART mentioned that he had made some investigations to ascertain how far it was possible to obtain speed regulation with shunt-machines by introducing a resistance into the field-coils and so reducing the available magnetic induction. In some types of machines it was possible to obtain 25 per cent. increase of speed, while with others only a slight increase was possible, further experiment being stopped by injurious sparking at the brushes.

Mr. Mavor.

Mr. H. A. MAVOR, in reply, said that the curves accompanying the paper were plotted from calculated results, and pointed out that in practice the motor would not probably be carried through the range of load shown on the curves; they were drawn to give a more complete

grasp than is usually available of the comparative characteristics of shunt- and series-motors. The curves are plotted on the lines which have been adopted for recording the characteristics of street rail-motors. He stated that the arrangement of switching the motor on and off was familiar to him, but that he did not consider it safe to leave a high-tension armature in circuit without including also in the circuit a non-inductive resistance through which the current could die down on switching off. Mr. Mavor.

In reply to Mr. McWhirter, Mr. Mavor pointed out that the power required to drive shafting and gearing in a bench of sewing-machines bore so large a relation to the total power required that he did not think it would be found that there would be any injurious racing with decrease in the load. In reply to Mr. Coates, he pointed out that the machines which he had specially referred to as being inefficient users of power were engineering tools where a considerable amount of gearing was introduced between the power and the work, both for feed and traverse, and that it was in such cases as these that the power actually expended on cutting bore a comparatively small relation to the total power delivered to the machine. In reply to Professor Watkinson, he stated that he was not conversant with the details of Mr. Ferranti's arrangement for speed variation, but that it was not difficult to design a motor the speed of which could be varied by adjustment of the brush position, and instanced cases where this had been done and also where the electromotive force given by a dynamo had been varied from full voltage to non-excitation without sparking.

NEWCASTLE LOCAL SECTION.

INAUGURAL ADDRESS BY THE CHAIRMAN.

Delivered May 15, 1900, *by*

A. W. HEAVISIDE, Member.

INTRODUCTION.—In addressing you at this the first meeting of the Newcastle Section of the Institution of Electrical Engineers, I have, in the first place, to thank you for the unexpected honour you have bestowed upon me in electing me your first chairman. There are other members of this Worshipful Company worthier than I, whose modesty has thrust the unaccustomed duties upon me; but, having accepted the position, I will do what I can to further the success of this Section of the Institute, whose interests are those of the fascinating industry in which we are all engaged, in such fashion as my slender attainments will permit.

I have thought that as the establishment of a Section of the Institute in the ancient city of Newcastle-on-Tyne earmarks both the place and the time, that, perhaps, it would not be altogether uninteresting to the members if an effort were made to locate in some degree the position held by the District, of which this city is the centre, in the electrical industry. To do this, by way of historical introduction, it is not necessary to go back to Thales of Miletus and his excited amber, but only to a more recent period which is scored all over with the honourable marks of discoveries and inventions which have mainly assisted in making electricity the servant of man.

WHO BUILT UP THE TELEGRAPH.—As we all know, the pioneer industry is that of the electric telegraph, which knits the world together, and is both the oldest and at present the most indispensable of all the applications of electricity. Like our venerable Queen, it came to the throne in 1837, where, similarly, it has reigned, with ever-increasing beneficence, ever since. In the circumstances, and out of reverence for those who have done so much to aid present successes, a few moments can be well spared for just a glance at the discoveries and inventions needed for the evolution of the electric telegraph in its simplest form. All that is needed to signal the thoughts of the community from one place to

another is the combined use of three things, built up of many parts—a source of electricity, a conductor of electricity, and an indicator of electricity. Simple enough in these modern days: every electric bell-hanger knows that, and sometimes knows how to do it! But consider what a mountain of labour and patient investigation over more than a century, from 1729 to 1837, before the discoveries of great men were combined by the Inventor in the production of a practical electric telegraph.

Just look askance over one's shoulder down the back entry of time. There are always the shadowy forms looming largely on the horizon of Gray, an Englishman, who, in 1729, discovered the difference between conductors and insulators, using moistened pack thread for the former, and silk loops for the latter; of our great Anglo-American Franklin, who, in 1752, with his kite in the sky, conducted the lightning to the earth, thus establishing its identity with electricity; of Galvani and Volta, the eminent Italians, who, from 1786 to 1789, developed one source of electricity, namely, "the Chemical Battery." Here we may pause for a moment, having learnt in seventy years how to produce and how to conduct electricity in an elemental manner. Then comes the achievement of a practical indicator of electricity—how to get it?—a somewhat complex problem. A needle, or armature of steel or iron, magnetised permanently or temporarily from any source, and responsive to every change in its electrical environment, yet controlled by man, a thing that no one at that time knew anything about practically, in a combined sense, though many lent wings to their imaginations in the effort to mentally satisfy the problem.

THE MAGNETIC NEEDLE.—I promised not to go so far back as Thales of Miletus, but, again, reverence for the past unexpectedly commands that I should go back farther still, but just for one moment, if only to say that the ancient Chinese in past ages apparently knew all about its properties. So to start fair, we find that Oersted, the Dane, in 1819, with the magnetic needle ready to his hand, made the first step; he deflected his needle by means of a current in a wire parallel with it, proving that currents and magnets have similar properties, whilst Ampère, the renowned Frenchman, in 1820, made another step by discovering

that a suspended coil of wire carrying a current was a magnet. Then France, in the same year, in illustrious Arago, provided another link by temporarily magnetising soft iron during the presence of the current; finally Sturgeon, the sturdy Englishman, in 1825, made a last fundamental step, by placing soft iron into Ampère's coil, produced the electro-magnet of to-day, which in conjunction with a needle, or armature, is the basis of telegraphy and many other things.

THE INVENTION OF THE TELEGRAPH.—The mental activity of the twelve years following, which gave a clearer grasp of the laws of electrical action, is marked by the mere mention of the names of such giants in science as Gauss, Weber, Coulomb, Faraday, Henry, and Neumann, who also, in one way or another, contributed to the almost simultaneous invention of practical electric telegraphs in three great countries, viz., England, Germany, and the United States of America in the year 1837. June, of that year, gave the world Cooke and Wheatstone's 5-needle telegraph; July, Steinheils' needle, bell, and printed marks telegraphs; and, October, Morse's marks embossed on paper. With many apologies to the names of the unnamed illustrious ones, I must conclude this stride over a century and endeavour to show Newcastle's place in telegraphy and kindred things. But in passing, I would beg you to observe, incomplete though the list may be, how suggestive is the array of names and countries to which the contributors belong. How ubiquitous is science and its votaries! What a true cosmopolitanism and universal brotherhood exists, which took the Institute to Switzerland last year, and will certainly take most electrical engineers, including myself, to Paris this year!—forgetful of yellow-press politicians and their narrow statesmanship, which contract the humanities and tend to embitter one nation against another. I am sure that my audience is with me in crying, "Away with all such narrow and sordid feelings; let us breathe a purer atmosphere on a higher platform!"

THE APPLICATION OF THE TELEGRAPH.—In 1837, as I have said, a practical 5-needle telegraph was invented, but was soon simplified to two needles only. This invention was slow of appreciation, for seven years elapsed before a Joint-Stock Company was established to exploit it. How-

ever, in 1844, the Electric Telegraph Company started the combined railway-and-public-service, and in two years their operations extended to this neighbourhood, where they established a double-needle circuit from Gateshead to York. At that time thirteen shillings and fourpence was charged for a message of twenty words from Gateshead to London, *viâ* York. The basis of this charge needs to be placed on record. One penny per mile for the first fifty miles, one halfpenny per mile for the second fifty miles, and one farthing for every additional mile, with certain extras for porterage and addresses. Now, as is well known, since 1885, twenty words cost sixpence to any place in Great Britain and Ireland. The nimble sixpence is the key to the carriage of lightning thoughts throughout the land. In 1849 the high-level bridge across the Tyne was completed, and with it came the establishment of an office on the Sandhill, about the site of Gosmas' restaurant. Newcastle's first direct connection with the Metropolis was in 1851, when it was temporarily established with the first International Exhibition in Hyde Park. The double-needle now began to give way to the single-needle and the Bain Chemical recorder, which were succeeded by the Morse embosser in 1858. In 1853–4 the Magnetic Telegraph Company, using Highton's single-needle and Bright's acoustic bell system, a forecast of the American sounder, came to Newcastle with transmitting centres at Leeds and Carlisle, competitively reducing the before-named thirteen and fourpence to three shillings as the Newcastle-London rate. Another ten years, and 1864 saw the shilling, or United Kingdom Telegraph Company in local existence, using the Morse printer and the beautiful Hughes typewriter, invented in 1853–4–5, which brought to Professor Hughes honourable distinction in every civilised country but his own.

But in 1867 a great advance was made: up to this time the usual controlling force in all signalling by battery contact, or interruption, was the hand of the operator which limited the speed of working on any wire to thirty or forty words per minute at most. Wheatstone knew that the speed of electric travel and the carrying power of the wire were beyond the needs of man, whilst the work then *got out of the* wires was below man's needs. His problem

was to save both new wires and time by the introduction of a mechanical device, by means of which an electric battery contact could be made, broken, or reversed with great speed. These battery contacts represented signals, the familiar dot-and-dash of the Morse alphabet, which were recorded on a paper tape at one or more places simultaneously. He achieved this by first punching through a paper tape a series of contact-holes to correspond with the dots and dashes which form the alphabet, and by passing this tape through a clockwork reversing battery contact-maker, transmitted long or short currents along the conductor which, at the distant end, entered an electro-magnetic receiver, whose responses were recorded in dot-and-dash ink marks. This invention was worked out by the aid of that most estimable gentleman, Mr. Augustus Stroh, a veteran pioneer in the scientific construction of all philosophical and electrical apparatus, whose understanding of means to an end in electrical mechanisms stands pre-eminent. This Wheatstone automatic apparatus was first introduced for practical work in this country between Newcastle-on-Tyne and London, Edinburgh and Glasgow following after. Daily practical work is carried on with it at a normal speed of 330 words per minute on the local wires of this district, and between London and Birmingham, 600 per minute. Of course, if duplexed, these figures become about 550 and 1,000 respectively.

In 1870 the Post Office acquired the telegraphs and introduced universal shilling telegrams, followed in 1885 by sixpenny telegrams. By the kindness of Mr. T. Stevenson and Mr. A. Mellersh, the Post Office surveyors of this district, I am able to give the following figures of the traffic of this district for the year ending March 31, 1900:—

Telegrams :—Forwarded.	Received.	Transmitted.	Total.
3,034,030	3,193,890	2,523,971	8,751,891

The first column is the money-earning one, and shows that, taking the population of the district at 2,000,000, rather more than $1\frac{1}{2}$ messages per head of the population originate in the district per annum, but taking the forwarded and eceived, the traffic of the district is rather more than three per head of the population. The wires provided in the district by the Engineers' Department amount to 14,889

miles, carried along 1,794 miles of route; 287 post offices absorb 823 sets of telegraph apparatus, and 1,244 private offices absorb 1,418. The National Telephone Company's

FIG. 1.

amount to about 5,000 Exchange connections, using 6,657 miles of wire serving 32 Exchanges. Figure 1 shows the telegraph offices in direct communication with Newcastle at the *present time*, equalling 155, served by 104 wires,

exclusive of wires that pass through Newcastle *en route* for other places.

To continue our story, of course duplex and quadruplex telegraphy are largely employed. Gintl, in 1853, invented duplex telegraphy, but it did not come into practical use until Stearns applied a counter Kick condenser to it in 1873. O. Heaviside suggested quadruplex telegraphy, which was developed by Edison and others, and was followed by the multiplex of La Cour and Delaney. In duplex telegraphy, as we all know, the outgoing current divides equally upon the apparatus nullifying local responses; consequently it is left free to respond to currents from the distant end only. Quadruplex is the addition to the latter of currents of two strengths, with selective apparatus at each end, which responds only to the current suited to it. In multiplex telegraphy, six or more instruments are synchronously and successively connected to one wire with such short intervals between each connection that practically each operator has an independent use of the wire. Newcastle has not risen to the dignity of the use of this apparatus at present. The search for various methods of multiplex telegraphy led to the use of vibrating reeds of different responses. A reed may be a tongue of iron before an electro-magnet. Here we have the magnetic telephone *in nubibus*. The tongue may respond to vocal vibrations and be developed into a membrane of disc shape still more responsive. It is remarkable that there is a mysterious connection between the search for multiplex telegraphy and telephony, which just preceded the invention of the telephone.

THE GREAT NORTHERN TELEGRAPH COMPANY.—It may be usefully mentioned here that, in 1868, the importance of Newcastle-on-Tyne telegraphically was greatly increased in consequence of the Anglo-Danish, now Great Northern, Telegraph Company commencing operations. Their first cable was laid in 1868, by Mr. R. S. Newall, between Newbiggin-by-the-Sea and Sondervig on the west coast of Jutland, 335 nautical miles. The second cable was laid in 1873, between Newbiggin and Hirtsholson on the same coast, 430 nautical miles. The third cable was laid in 1880, between Newbiggin and Arendal in Norway, 520 nautical miles; and their fourth and last cable was laid in 1890,

between Newbiggin and Marstrand in Sweden, 509¾ nautical miles. In addition this Company have two land lines to London, and one to Peterhead in Scotland, in connection with another submarine cable to Norway. The apparatus employed is one of remarkable delicacy (a first cousin to Lord Kelvin's siphon recorder, which is still more sensitive), called the undulator. Indeed, so sensitive is the arrangement which works through the cables and the land lines to Scandinavia at a normal speed of 80 words per minute simplex and 120 duplex, that great care has to be taken to avoid lateral inductive effects. Mr. John Mygind, who has ably administered locally the affairs of this Company since 1868, can only view the introduction of electric traction with apprehension.

The Commercial Cable Company and the Anglo-American Cable Company have each land wires to Newcastle to feed their cables.

Going back to 1859–60, at this time the Universal Private Telegraph Company exploited the Wheatstone ABC telegraph for private conversation at a rental. This was introduced into Newcastle in 1863. Out of it developed the ABC Exchange system, by which private circuits converging on a centre were joined together for conversational purposes. This was the forerunner of all telephone exchanges. Printing Court Building is the historic spot where this was first done in this country in 1864. Sir William Armstrong and Company, Thompson and Boyd, and Charles Mitchell and Company were the first to keenly realise its advantages. This magneto-electric telegraph took eighteen years to develope, from 1840 to 1858, and again the hand of Stroh helped Wheatstone. This instrument is really the baby of the alternating inductor dynamo of Mordey and others of to-day.

But in 1877 came the epoch-making telephone, the receiver perfect at a bound from the hand of Bell, our Anglo-American. Alexander Graham Bell somehow stepped in front of Elisha Gray, who was first in the field. The instrument has appealed more powerfully to the mind of the thinker as a physical demonstrator of the existence of electrical vibrations than anything before and up to the time of Herz in 1887. This instrument made the detection of long-distance induction practical for telegraph purposes,

and preceded the no less extraordinary detector of Branly and others called the coherer. So great was the interest excited by the invention of the telephone, that in May, 1877, two of my staff, Mr. Frank Reid and Mr. W. R. Smith, needed no initiative to make the first telephones in this district from parts of the ABC telegraph. In September of the same year Alexander Graham Bell paid a stimulating visit to Newcastle, where already, with all our might, we were trying to understand the sometime called "philosophical toy." What to do with it, the pesky thing, with its marvellous sensitiveness? How to get it under control? It was such a libertine in tapping all hitherto invisible and unknowable electrical procedures, showing that beneath the

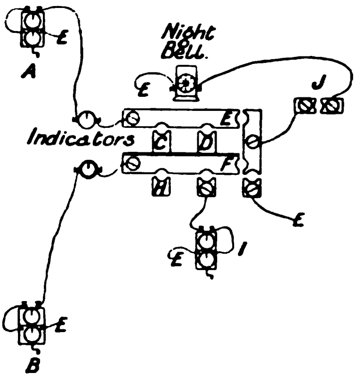


Fig. 2.

outward calm the Heavens, the Earth, and the whole Cosmos were in ceaseless activity of vibration, partly Nature's, and partly that part of Nature, Man's.

A little bit of soft iron encircled with wire and a wee ferrotype iron diaphragm fixed in a case became the revealer of the mysteries until then only deductively dreamed of by the physicists, such as Maxwell, Lord Kelvin, and, perhaps I may be permitted to add, Oliver Heaviside, and others, running riot with the imagination of all investigators and forecasting that in the long run there is no articulate secret that may be unknown, the irrepressible telephone picking up all vagrant sounds of mechanical or electrical origin, like the sleepless Fury Tisiphone at the gate, always on the watch to record, but not to avenge!

THE MICROPHONE.—Then Hughes, in 1878, crowned the telephonic edifice with the invention of the pencil microphone, nearly as we now have it, making a gift of it to the world, thus paying tribute to humanity, as he has since done by bequeathing his great wealth to the London hospitals. Of course from the first the days of the ABC were numbered, and the problem how to get the telephone under control stared one in the face. Just let us consider the place the telephone has in the world.

DEFINITION OF TELEGRAPHY.—Electric Telegraphy is the transmission and reception by electrical agency of inarticulate thoughts by a pre-arranged code of signals representing the alphabet, say five signals per word. It involves eight elemental steps:—1. The thought; 2. Its writing out; 3. Its conveyance by messenger to the telegraph office; 4. Its transmission by dots and dashes over the wires; 5. Its reception by dots and dashes over the wires; 6. Its re-writing out; 7. Its conveyance by messenger to the recipient; 8. The understanding of the written thought by the recipient. 4, 5, and 6 may be, and are, multiplied enormously by repetition where the service is indirect. Though clumsy, it has done and does good work, is interesting in its complexity and limited in application.

DEFINITION OF TELEPHONY.—Electric Telephony is the instantaneous interchange by electrical agency of vocalised thoughts, charming in its simplicity. It sufficeth not in this country through the greed of monopolists and imperfections in exploitation. This time will cure, as in application it is unlimited. The house-to-house telephone, nay, the room-to-room telephone is its inevitable goal. From May, 1877, to December 24th, 1880, much telephonic research work that would take too long in the telling was done at Newcastle, as well as elsewhere.

As it is with Newcastle that we are mostly concerned in this address, it behoves one to touch, alas! too lightly, in this lightning survey on what was locally done as the result of the midnight oil. We can only stop to record one observation which, though it attracted little attention at the time, was eventually more far reaching in its consequences than any other.

FORECAST OF THE BRIDGE SYSTEM.—In May, 1877, a local circuit was made up of four lines converging on an

Umschalter switch. When conversation was held with the pegs inserted as in Fig. 3, A, better speech was obtained between the mechanics' shop and the battery room than when the pegs were inserted as in Fig. 3, B. That it was so we knew. Why it was so only revealed itself as time disclosed its importance.

On December 24th, 1880, judgment was given that a telephone was a telegraph. This opened the door of the department for its exploitation. In 1881 a Post Office Exchange was opened at Sunderland. It was joined up on the usual plan with the intermediate apparatus in sequence, upon double wire twisted loops, as first suggested by Professor Hughes. The apparatus in sequence choked the speech, threw the line out of balance, let in lateral

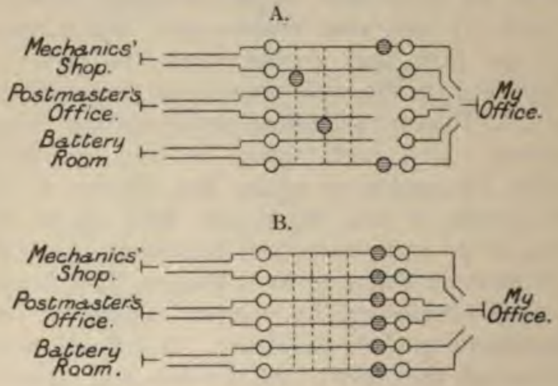


FIG. 3.

induction, undoing the benefit of Hughes' twist. Shift was made in this district, as all over the world, with this arrangement, its imperfections being condoned. With underground work it died at four miles length; by putting one intermediate on one side of the loop and another on the other side, its life was resuscitated to eight miles of underground work, and there speech stopped dead. But, as had already been proved, there was one, and one way only, to secure telephonic speech unlimited as to distance and free from vagrant sounds. That way was hidden in the elemental principle contained in Diagram A, which, if drawn out straight, threw off its disguise and gave this—Fig. 4—the intermediate apparatus in bridge across the line. Savants

looked askance; it abrogated Ohm's law; why, it short-circuited the line!

FINAL SURVIVAL OF THE BRIDGE SYSTEM.—However, its efficiency was drastically put to the proof by partial use in 1881; it survived the whips and scorns of time, and was finally adopted *in toto*. Stockton was the first exchange entirely joined up in this manner; a new post office involving new construction was the opportunity. This exchange was opened on the 26th of January, 1885. The kernel of the system is that, by putting apparatus of great impedance at the intermediate points, vocal high-frequency telephonic undulations gave the short-circuit the go-by, whilst low-frequency call-signal currents operated the signalling indicators at the bridges *con amore*.

The operating in the Post Office system is arranged so that over-hearing on the part of the switch-clerks is unnecessary. A system of automatic block-signalling by means of needle deflections tells the operators all they need to know; hence all the conversations are heard only by

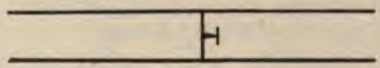


FIG. 4.

those whose property they are, the principals in the transaction. The clever application of hard-earned prior knowledge ensures business success; but if it leaks by the way, what then?

TELEPHONE TRUNK WIRES.—Telephone trunk wires were early introduced in this district, the first being between Newcastle and Sunderland, 1883. In October, 1896, when the National trunk wires became the property of the State, the Newcastle service had already reached 33, to which had to be added the National, giving a total of 68. Now they reach 72, and Fig. 5 shows to what towns direct communication exists, 14 in number. If to this be added all the towns now served by telephone trunk wires, the total is 303. In the Tees to Tweed district, for the year ending March 31st, the number of trunk calls reached 3,127,689. Post Office and National Local Exchange calls reach about 12,000,000 per annum.

LONG DISTANCE INDUCTION BY THE TELEPHONE.—Then came 1886. As already referred to, the telephone detection of inductive effects at long distances is marked. This is the so-called wireless telegraphy of the electromagnetic order. It was always there; most people knew of it from the days of Faraday and Henry in 1831; but what they did not know was its extent, which, after all,

FIG. 5.

depends upon the force of the source, the delicacy of the detector, and, to some extent, the opacity or transparency of the medium. The telephone always asserted itself unblushingly in responding impartially to vagrant electrical effects. In pursuit of this Will-o'-the-Wisp, most people's trouble was to find time to step on one side from the busy humdrum of life to follow, much less exhaust, any one of

the many avenues that revealed fascinating horizons that led to the joys of finding out Nature's secrets and gave beauty of understanding.

In the Newcastle Battery Room, as recorded in the *Journal of the Society of Telegraph Engineers*, vol. x. p. 21, January 26th, 1881, in December, 1880, one had only to walk about the room with a telephone and a coil of wire to read the Morse signalling from every battery in use. This work was resumed in 1886 by a series of experiments which had for their object the discovery of four things: (1) At what distance from a primary parallel could these effects be detected on the telephone? (2) How much of the effect was conductive? (3) How much was inductive? (4) Were all bodies transparent to them? On April 14th and 15th, 1886, fourteen years ago, on the Newcastle Town Moor, I proved, with 120 reversals per second and half an ampere of current, that it might be both, or whichever you pleased—inductive or conductive—dependent upon whether earth-returns or insulated metallic returns were employed, also that where earth-returns were used the earth could be tapped by driving the two ends of four yards of wire with a telephone in circuit into the earth. It was also proved that, with a secondary or with a primary only connected to earth at one point, static effects could be easily detected though diminished in loudness. Further, it was proved that, if the distance from the primary was more than the length of the primary, the effects diminished in loudness very rapidly.

From this time until August 15th, 1886, the changes upon the above experiments were rung in many ways, always extending the distances, ending in Morse-speaking across forty miles of country, between Shap and Gretna on the west and Newcastle and Jedburgh on the east, produced by interrupting the vibrations with a Morse key. Up to this time the primary wires were usually single wires put to earth at each end, and the secondaries insulated squares or rectangles, and the difficulty was to get a space large enough to lay out insulated wires on the surface without exciting the hostility of the tenants of the Northumberland Moors. However, Mr. Hugh Andrews, of Swarland Park, came to the rescue and placed his estate at my disposal.

Proof Inductive, not Conductive.—Here it was, in the last week of August, 1886, that with two miles of in-

sulated wire laid out as two squares of quarter-mile sides, and a quarter of a mile apart, or half-mile centres, that articulate telephonic talk was inductively held between one square and the other. Hearable with closed circuits, difficult to hear, but present, with open circuits. Of course, this test was with undulatory currents of microscopic value and forms the highest testimony of the extraordinary sensitiveness of the telephone. This was followed up by telephonically speaking from the workings of Broomhill Colliery to a triangle of insulated wire, three-quarters of a mile each side, laid roughly parallel over colliery workings, the medium for the waves to travel being 360 feet of the crust of the earth. Of course, as every one knows, with the all-important addition of Evershed's call, this electro-magnetic system has been developed and applied practically by Sir William H. Preece, and is in use between Flatholm and Lavernock in the Bristol Channel.

COHERER WIRELESS TELEGRAPHY.—But in 1897–8–9 Marconi has, by combining the labours of Branly, Righi, Oliver Lodge and others, coupled with his own clever insight into the subject, signalled over great distances, truly without wires, for really what wire he does use may be considered as part of his electro-static apparatus. Of Marconi and his system, much may be expected, and all present must rise in admiration of the persistency and pluck of this young Italian in experimenting and experimenting in every possible way to achieve long-distance speaking with practical success.

In connection with the coherer which coheres in response to an electric flash, it is singular that Mr. Augustus Stroh has observed something akin in the adhesion of surfaces when traversed by an electric current (see the *Journal of the Society of Electrical Engineers*, vol ix. p. 182); and it is sad, that misguided by the savants, Professor Hughes, the cruelly-neglected scientist did not go further in anticipating wireless telegraphy than was brought to light last year. It is a pity that, like Cavendish, he did not publish his researches at the time.

We must now hurry forward to see where we stand with the other great electrical industries, better known than telegraphs and telephones in one sense, arising out of their control not being that of the State, or of the monopolist, but everybody's business.

NEWCASTLE INVENTIONS. LORD ARMSTRONG.—Let us ask what is Newcastle famous for in original work: well, first we have Lord Armstrong's hydro-electrical frictional machine of 50 to 60 years ago, showing the electrification produced by steam rushing through an orifice; and then we have Lord Armstrong's *magnum opus* of 1897 on the "Electrical Movements in Air and Water." Who in Newcastle is not justly proud of this venerable citizen, mathematician, scientist, engineer, and above all, one who does not live for himself alone! The giver of parks and gardens, and the creator of the greatest private arsenal in this and many other countries.

JOSEPH WILSON SWAN.—Second, in the order of date, comes Joseph Wilson Swan, F.R.S., of Newcastle-on-Tyne, the inventor of the Swan lamp which assumed practical form in the autumn of 1880. From the days of King, in 1845, to the days of Swan, in 1878–80, many tried their hands at getting light from incandescent platinum, or carbon *in vacuo*. But whilst all they did established the soundness of the principle, nothing they did brought more than disappointment from a practical point of view. Mr. Swan himself laboured and experimented with the incandescent lamp in the decade 1850–60 with like result. He used carbon strips in loops and spirals, carbonised in Wallace's Forth Banks pottery kilns in crucibles filled with powdered charcoal, but the available mechanical air-pumps gave a bad vacuum for such a purpose. Yet, at this early date, Mr. Swan had grasped the necessities of the case, a cheap source of electricity, an excellent filament, and a good vacuum.

By 1877–8, the dynamo was entering upon a vigorous life. Arc lamps were being introduced daily, Jablochkoff the unrewarded being the first. In 1864 and 1870 Pacinotti and Gramme produced direct currents from ring armatures, Wilde's dynamo of 1866, and Wheatstone's and Siemens' dynamo self-excitation of 1867 were beginning to bear fruit. The telephone was invented. Planté batteries were coming to the front. In 1873–6 Crookes had shown how to produce high vacua with the Sprengel pump in his beautiful radiometer. Electricity was in the air, sparkling, and iridescent as any sunrise. In fact, hopes ran high and the electricians of the day felt how beautiful was the world if only rightly

taken. In these stimulating circumstances Mr. Swan resumed his researches in incandescent lighting, determined to solve the problem of the hour, viz.: the sub-division of the electric light, by the production of a lamp for domestic use that would, as it did, outrival Aladdin's lamp in the riches it has brought its exploiters. Early in 1879, Mr. Swan, whose charming acquaintance the telephone introduced, brought some lamps to the historic Post-Office battery room for measurement of current and resistance, when it was at once apparent that filaments made from cardboard parchmentised and carbonised were unsatisfactory, their resistance was low, the current absorbed was high, and the bulbs quickly blackened. At these interesting and never-to-be-forgotten tests, Ohm's law and multiple-arc were much in evidence, all theory and experiments pointing to low-resistance conductors and high-resistance filaments as the solution of the domestic lighting problem. The filament was the crux of the problem, and as late as April 3rd, 1880, after much work in the meantime, taking four lamps as samples, their cold resistance was only 38, 45, 47, and 65 ohms, and $3\frac{1}{2}$ amperes only made them red-hot or a little more. But on June 15th, 1880, Mr. Swan gave me the pleasure of testing one of 120 ohms, and another of 118 ohms resistance. This happier result was brought about by carbonising crotchet cotton, a true filament. (In the meantime, it is interesting to note that Edison was more successful in his world-wide search for a vegetable fibre as a filament than Diogenes was in his search for an honest man. But then he did not use candles.) After this, Mr. Swan made such progress, that by the autumn, Lord Armstrong's Cragside House was installed with twenty lamps; and, on November 24th, 1880, Mr. Swan brilliantly illuminated the auditorium of the Institution of Civil Engineers, in Great George Street, Westminster, to the delight of a distinguished audience of the members of the Society of Telegraph Engineers and Electricians, now the Institution of Electrical Engineers.

Mr. Swan, during these three years of labour, was running a neck-and-neck race with Edison and Lane Fox, each on independent lines, none the less honour to each of them; and, all Newcastle men are proud of the distinction that in their city one of the most valuable inventions of the

Victorian Era was conceived and developed to a practical issue by Joseph Wilson Swan. Since then, at Bromley, in 1884, Mr. Swan invented the cellulose, or nitro-cellulose filament squirted into a coagulating medium, such as alcohol, without which the high voltage copper saving lamps of to-day would not be. This material is also the basis of the artificial silk of to-day. It is now produced in a viscous form that can be moulded, enormously increasing its use in the arts.

It is worthy of remark, that Swan foreshadowed the Faure pasted plate (which was brought in a box to Lord Kelvin from Paris containing a million foot-pounds of energy). At his lecture before the Literary and Philosophical Society of Newcastle-on-Tyne, on February 2nd, 1879, when exhibiting a crude lamp, he spoke of the need for storage and showed a modification of the Planté cell, in which there was the novel feature of spongy lead having been deposited around the frillings of the peroxide element previous to oxidation to form what is now called the positive element.

SUNBEAM LAMP.—Swan's domestic lamp suggested a large incandescent lamp as a rival to the arc, and early in 1887 Mr. T. W. Edmondson, a disciple of Mr. Swan's, succeeded in making the Sunbeam lamp, of from 100 to 500, or even up to 2,000 candle power; which, as a survival of the fittest, has managed more than to hold its own with its rivals. It is deserving of honourable mention as a Tyneside development, and, as in other lamps, the filament was the crux of the problem.

But to the Hon. Chas. F. Parsons the district has earned distinction by his invention in 1876–1884 of the Turbo generator (a far more original work than the last-named). For the horse-power developed, it is perhaps the lightest machine in existence, occupying little space, perfectly elastic, dancing in its bearings, and said to cost little to maintain mechanically. It is idle for me to attempt to describe this and so to do what is done so much better by its inventor whom I shall now ask permission to quote: "The first condensing turbine of the radial flow type was of 200 horse-power and at a speed of 4,800 revolutions per minute, drove an alternator of 150 kw. output. It was tested by Professor Ewing, and the general result of the trials was to demon-

strate that the condensing steam turbine was an exceptionally economical heat engine. With a steam pressure of 100 lbs., the steam being moderately superheated, and a vacuum of 28 inches of mercury, the consumption was 27 lbs. per kilowatt hour, which is equivalent to about 16 lbs. of steam per indicated horse-power. This result marked an era in the development of the steam turbine and opened for it a wide field, including some of the chief applications of motive power from steam. At this period (1892) turbine alternators of the condensing type were placed in the Newcastle, Cambridge, and Scarborough Electric Supply Company's stations, and soon afterwards several 600 horse-power of the non-condensing parallel-flow type were set to work in the Metropolitan Company's stations, where the comparative absence of vibration was an important factor. Turbine alternators and turbine dynamos of 2,500 horse-power are now in course of construction in England and the United States and larger sizes are in prospect.

"A turbo alternator manufactured at Heaton Works, Newcastle-on-Tyne, for the Corporation of Elberfield in Germany, was tested a few days ago by a committee of experts from Germany, Professor Ewing also being present, with the following remarkable results:—At the full load of 1,200 kilowatts, and with a steam pressure of 130 lbs. at the engine, and 10° C. of superheat, the engine driving its own air-pumps, the consumption of steam was found to be at the rate of 18·8 lbs. per kilowatt hour. To compare this figure with those obtained with ordinary piston engines of the highest record with which I am acquainted of the ratio of electrical output to the power indicated in the steam engine, namely, 85 per cent., the figure of 18·8 lbs. per kilowatt in the turbine plant is equivalent to a consumption of 11·9 lbs. per indicated horse-power, a result surpassing the records of the best steam engines in the production of electricity from steam."

The remarkable feature of the modern turbo-generator is its utilisation of the expansive force of steam in a series of steps by which its initial velocity of 2,462 feet per second is reduced to a final velocity of 405 feet per second or one-sixth. Take a waterfall, it is theoretically possible to utilise the head without loss. Well, similarly, the fall could be used in a series of steps, the water losing its

potential energy with each step. So it is with the turbo-generators. Take steam at a given pressure, with a corresponding velocity, provide, as in the turbo-generator, a series of steel-guide blades, and a corresponding series of interposed blades for the steam to impinge upon, the diminution of pressure with each step being probably but half a pound, the resultant circumferential velocity is one that is easily dealt with in practice, say 2,400 revolutions per minute which allows direct coupling. On the other hand, if all the energy is absorbed in one wheel, the resultant circumferential velocity gets beyond practical control. In the laval turbine, its 30,000 revolutions per minute must be reduced by gearing when practically applied, this limits security from break down to machines within and up to 100 H.P.; beyond that, disaster follows. In the Parsons turbo-generator, the centre of gravity of the moving mass coincides with the centre of the figure, or the geometrical centre of gravity on account of the provision made for lateral displacement.

Electric Lighting.—At the present time, ten large towns in this district, including Newcastle, Gateshead, Sunderland, South Shields, Tynemouth, Wallsend, Middlesborough, Stockton, Darlington, and West Hartlepool, have either electric power-houses in active operation, or in course of rapid construction. But I cannot stop to say much of them except the pioneer ones of Newcastle-on-Tyne. In this city we have two services, that of the Newcastle and District Electric Lighting Company, projected by the Hon. C. A. Parsons, late in 1888, and that of the Newcastle-on-Tyne Electric Supply Company, projected by Dr. Robert Spence Watson in 1881, but not brought to a practical issue until 1888.

Taking the Parsons' Company first. The original turbo-generators are employed at a speed of 4,800 revolutions, the later machines only at 2,400 revolutions with a pressure of 1,050 volts, and a frequency of 80 periods. Last year the Companv generated 1,571,650 units, and sold 963,622 units, and the peak reached 756 amperes upon an installation of 1,490,130 watts, the number of consumers being about 400.

The Newcastle-on-Tyne Electric Supply Company's plant is the very antithesis of that of its companion Company, the "District" where, as described, it is light, having velocity and elasticity in lieu of momentum or

inertia of mass. That of the "Supply" is slow-moving and heavy. Horizontal compound long-stroke Corliss engines of 70 to 80 revolutions, and Mordey dynamos up to 150 kilowatts each. The engines, which are of Robey and Company's well-known make, and fitted with their trip expansion gear, have performed admirably, as it will be acknowledged by all present, when I state the following facts. That during the eleven years working, no main bearing cap on any engine has been lifted, and no new part has been supplied, excepting piston rings, and all the engines are now in first-rate working condition. The steam consumption may be said to average 16 lbs., with the low vacuum of under 20 inches. The larger units, of course, giving the best results. Similarly, the Mordey uniphase dynamos, 2,100 volts, have been equally successful. They are nearly self regulating, the larger units being the most satisfactory. As is well known, they are remarkably efficient, having the characteristic of steadiness under all loads. In 1899, the Company generated 1,517,311 units for the supply of an installation of 1,924,680 watts, reaching a peak of 416 amperes upon a sale of 990,551 units, the number of consumers being nearly 1,000.

Both Companies use rubber cables, the "District" Company using a complete net work of high-tension single cables in iron pipes, and the "Supply" Company a net work of concentric cables in iron pipes. Rubber insulated cables, if not starved, and treated properly, either wholly concentric, or wholly single pairs in a uniform atmosphere and a uniform mechanically protective environment give little trouble. Both Companies have cable ten years old still doing excellent service. Both Companies are developing direct low-tension services in congested places. Dr. Watson's Company has two accumulator substations, one in operation, another on the eve of practical employment. They are experimental. If successful, both technically and commercially they will mark an important step. Accumulators may be charged when there is no other use for the machinery, and employed to take the peak off, and, above all, during use, the possible troubles from running machinery are absent. The transformation losses are roughly comparable with the transformation losses in central distributing power-house schemes.

General Remarks on Electric Lighting.—Though so divergent in system the commercial success of both Companies is nearly the same. What is the public to think who do not look below the surface when they observe, however wide the variations in the electrical means to an end, the results are apparently the same. Like Max O'Rell, when speaking of nations, we must not at present say that one system of electric lighting is better than another, but that they are different. Clearly, a variety of conditions demands a variety of applications, nevertheless, it is only a question of time; the fittest will survive eventually and standard methods will crystalise. It was said of fascinating Cleopatra, "Age cannot wither her, nor custom stale her infinite variety." So it is with fascinating Electricity with a difference. Disaster does not follow her lovers—the British public pay the bill.

Nowadays, when electric supply is an assured success, every one can go to work with confidence, if only over-capitalisation is avoided. This is in the first degree the active danger of municipal undertakings governed by committees, all experts, of course. The need for dividends acts as the check in company undertakings, it tends to ensure both economy in capital, in production, and in maintenance. Production to serve a wide area of many needs assures continuity of load. This assures economy of production. An average of less than two hours daily use of all the machinery in established pioneer stations brings 8 per cent. dividend. But suppose we build anew on the experience gained. Cease to put down what now may be considered toy machines all in a row; and tobacco-pipe chimneys, jealously watched by vigilant smoke inspectors catching the specks upon sheets of white blotting paper. Emulate the courage of the Americans, the Swiss, and the Continent generally. Do not adopt expediency, either as to site or anything else. Then that peace of mind which belongs to solid far-seeing work overtakes the engineer and his friend the capitalist. They may smoke the pipe of peace with the imperturbability of a Turk and wait. It must come, every house will eventually have its electric light, as it will have its telephone. Purity, steadiness, and convenience save its extra nominal cost over other illuminants now, and continuous production will reduce gas companies' dividends

from lighting alone to something exceedingly small by and by. Hence the future of the electrical engineer augurs happily. He, the maker of this good thing, who only the other day, and alas even now, is so lowly rewarded for his labours, as not to be lauded by his neighbours.

On the distribution side of the question there is a danger. A large central power-house, if there is to be economy, means high-pressure alternate-current transmission of, say, 50 periods uniphase, if it will do (by no means improbable in the near future), and more phases if it will not, to as near the point of consumption as possible, large low-tension services are to be deprecated, especially where coal is cheap. The fewer the transformations the better, and preferably of the static, than of the dynamic order. In other words, do not have moving parts demanding human watchfulness, except where it is imperative, as for straight currents for electro-chemical work. Alternating currents needing no brushes will do all the rest. This may be rank wickedness to some trade interests, but it is the goal. Simplicity is what is wanted, not complication. There must be a point where the cost of long-distance transmission overtakes the economy of centralised production. That point has to be determined. Our grandmother, the Board of Trade, will have something to say about that. We are not as free as the winds as in Switzerland, where a dab of red paint on an insulator on a pole supporting multitudinous services, marks sudden death if disregarded, locating as it does, the extra-high-pressure service, and where magistrates rightly treat the idle breaking of an insulator as a crime, thus acting for the public interest as the British Post-office does when a penny letter is stolen. But the "great unpaid" treat insulator-breaking as a pastime: "Oh, you playful boy, don't do it again," or a nominal fine, is all that happens.

Motive-power by electrical agency is as convenient as going to the poulterer for your ducks, instead of keeping your own duck-pond. It is this principle that makes for success with power work. Nothing can stop it. What so cleanly, so simple, as getting all that is needed by turning on a tap. No space is occupied for installing a steam plant, no capital locked up in its purchase, and no standing charges for its maintenance. There is no waste during

holidays or strikes, and one care the less is borne by the user. This is the age of specialists, another name for the division of labour, without them the work of the world would not go on. Scatteration of effort is dissipation of energy. The user with the specialist at his elbow is relieved mentally, thus brain-power is released for concentration on his own speciality. What stands in the way is the loss at parting with a still useful old friend in favour of the new. It is the house-wiring question over again. Credit wiring, in the latter case at an enhanced cost in current to the user, until the capital is recouped is one solution. Similarly the development of good motors has reached that stage, that their hire and subsequent purchase will accelerate their adoption and eventual universal use. To produce confidence all that is needed is wise selection and judicious application.

ELECTRIC TRACTION.—Of electric traction one can speak as eulogistically as of the bicycle. It is the cheapest, pleasantest, and most healthy in its effects of all road locomotion. No loss of time at terminals, a travelling station that passes one's door. One halfpenny per mile in general, and one farthing for workmen's cars. Happily now it is booming in this country, and one sighs with relief that at last our conservatism has been broken down, and we shall soon be as our colonies and other civilised nations are. Only build strongly, make a good sightly workman-like structure, looking as if it fitted its purpose—then the cry of the æsthetic will cease and the cloud of the benighted disappear.

I would like to express my unqualified condemnation of the extremely shortsighted policy of not starting with a double track right away in the busy towns of this district. It is only excusable where there is lack of width, and that is rare. The imperturbability of the Turk will not overtake the exploiters or running engineers of that class of work. If they think so, as remarked in effect by the *Times* when prompted by Lord Salisbury's criticism of Treasury control of the War Office, they must be possessed of that incurable self-complacency that overtakes the public services of Great Britain.

Another word and this retrospect is done. The result of a circular I sent out to ascertain the number of persons

employed on electrical work in this district gives the following approximate figures:—

Telegraphs and Telephones	3,900
Electric Supply Co.'s	335
Manufacturers	2,400
Installers	219
Sundry Employment	146
Total	7,000

ORIGINAL COMMUNICATIONS.

NOTE ON AIR-GAP AND INTERPOLAR INDUCTION.

By F. W. CARTER, M.A., Associate.

The publication of Messrs. Hawkins and Wightman's recent dissertation on the "Air-gap Induction in Continuous Current Dynamos"[1] induces me to present to the Institution the following note on the subject of the fringe of lines near the edge of a pole-piece. It need hardly be pointed out in this place that the exact solution of the magnetic problem presented by a dynamo is impossible without an almost inconceivable addition to our present mathematical knowledge. Hence we are driven to making various assumptions about the shape of the lines of force in order to obtain a more or less approximate estimate of the strength of the field at the armature surface. Such assumptions often lead to sufficiently accurate results over limited regions, but are liable to break down where a solution is most wanted. Thus it is practically correct to assume that the lines of force pass straight across the air-gap, and that they form arcs of circles outside the air-gap—*so long as we are not near the edge of the pole-piece*, but the solution fails in the immediate neighbourhood of that edge. Messrs. Hawkins and Wightman's process of rounding the corner of the curve at discretion[2] can hardly be regarded as satisfactory.

In the following I propose to give the exact solution of some comparatively simple, though ideal, problems concerning the field of force near the edge of a pole-piece, in order to provide a criterion whereby to judge of the merits of the various approximate formulæ used in this connection, to indicate the order of accuracy that may be expected from the use of these formulæ, and to furnish a plausible means of correcting the results which they lead to.

The first problem to be discussed is the two-dimensional one of the lines of force from the pole-piece to the armature shown in Fig. 1, when the pole-piece is supposed to be at one magnetic potential, and the armature at another.

[1] See this Volume, p. 436, seq. [2] See this Volume, p. 438.

As the theory of conjugate functions is somewhat out of the province of the electrical engineer, I shall content myself with giving only so much of the mathematics as will enable those interested in such subjects to verify my results.

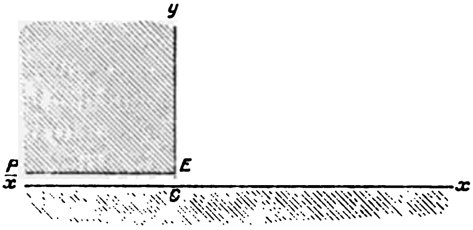


FIG. 1.—The Plane of $x\,y$.

Briefly then, we seek a potential function, ϕ, which reduces to the constant value ϕ_0 at the pole-piece, and to zero at the armature. Since the flux depends only on difference of potential, there is no loss of generality in assuming the potential at the armature surface to be zero.

Now the transformation—

$$z = \frac{2g}{\pi}\left\{\frac{\sqrt{a^2-\zeta^2}}{a} - \log\left(\frac{a+\sqrt{a^2-\zeta^2}}{-\zeta}\right) + i\frac{\pi}{2}\right\},$$

(where $z = x + i\,y$, $\zeta = \xi + i\,\eta$, $i = \sqrt{-1}$ and g is the length of the air-gap,)

converts the quadrant $\eta\,o\,\xi$ shown in Fig. 2, into the region we require, bounded by the pole-piece and armature of Fig. 1,—making O A into the pole face P E, A $\bar{\xi}$ into the side

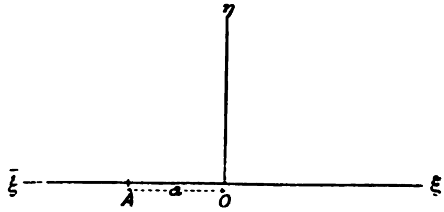


FIG. 2.—The Plane of $\xi\,\eta$.

E y of the pole, and $o\,\eta$ into the armature face $\bar{x}\,x$. For on O A, ζ is real, negative, and numerically less than a; thus Z = a negative real part + $i\,g$, *i.e.*, $y = g$ and x is negative—corresponding to P E; on A $\bar{\xi}$, z is a pure imaginary, between

[redacted]

$i\,g$ and ∞, *i.e.*, $x = o$ and $y > g$,—corresponding to E y; on $o\,\eta$, ζ is a pure imaginary $= i\,\eta$, and z is real, varying from $-\infty$ to ∞. Now if $\phi + i\,\psi$ be such a function of ζ, that ϕ is equal to ϕ_o along $o\,\xi$, and to zero along $o\,\eta$, then this function transformed into xy co-ordinates by means of the above relation, will give us the sought-for equipotential surfaces (ϕ = constant) and lines of force (ψ = constant).

The function having the above properties is given by

$$\zeta = e^{\frac{\pi}{2} i \left(\frac{\phi + \phi_o + i\psi}{\phi_o}\right)},$$

where e is the base of the natural logarithms, $(= 2{\cdot}718\ .\ .)$.

Thus putting $a = e^{\frac{\pi}{2}\frac{\psi_o}{\phi_o}}$, we get

$$z = \frac{2g}{\pi}\left\{\sqrt{1 - e^{\pi i \left(\frac{\phi + \phi_o + i\psi + \psi_o}{\phi_o}\right)}}\right.$$

$$- \log\left[e^{-\frac{\pi}{2} i \left(\frac{\phi - \phi_o + i\psi + \psi_o}{\phi_o}\right)}\right.$$

$$\left.\left. + \sqrt{e^{-\pi i \left(\frac{\phi - \phi_o + i\psi + \psi_o}{\phi_o}\right)} - 1}\,\right] + i\frac{\pi}{2}\right\}$$

We cannot express ϕ and ψ explicitly in terms of x and y, but we can nevertheless trace the equipotential lines, ϕ = constant, and lines of force, ψ = constant, from the above. We are, however, only concerned with the strength of the field at the armature surface, that is, with the value of $-\frac{\delta\phi}{\delta y}$, or of $\frac{\delta\psi}{\delta x}$, when y is zero.

Putting $\phi = o$, we get

$$x = \frac{2g}{\pi}\left\{\sqrt{1 + e^{-\pi\frac{\psi + \psi_o}{\phi_o}}}\right.$$

$$\left. - \log\left[e^{\frac{\pi}{2} i}\left(e^{\frac{\pi}{2}\frac{\psi + \psi_o}{\phi_o}} + \sqrt{e^{\pi\frac{\psi + \psi_o}{\phi_o}} + 1}\right)\right] + i\frac{\pi}{2}\right\}$$

$$= \frac{2g}{\pi}\left\{\sqrt{1 + e^{-2X}} - \log\left(e^{X} + \sqrt{1 + e^{2X}}\right)\right\} \quad . \text{ i}$$

TABLE I.

X	3	2	1	0·75	0·5	0·25	0	−·25	−0·5	−·75	−1	−1·5	−2	−2·5	−3
x/ξ	−1·71	−1·08	−·42	−·235	−·064	0·131	0·338	0·583	0·861	1.202	1·61	2·78	4·65	7·72	12·7
F/Fo	0·999	0·991	0·945	0·904	0·855	0·791	0·705	0·617	0·518	0·429	0·335	0·218	0·136	0·082	0·05
$\frac{\psi_1-\psi_0}{\phi_0}$	0	0·638	1·28	1·44	1·59	1·95	1·91	2·07	2·23	2·39	2·55	2·87	3·19	3·51	3·82

(dotted), obtained in the usual manner, *i.e.*, by assuming that, when x is negative, the force $\frac{\phi_0}{g}$, and, when x is positive $\frac{\phi_0}{\frac{\pi}{2}x + g}$. A comparison of the curves shows that the latter assumption makes the force too great at the edge of the pole-piece, and too small at a little distance outside the edge. Messrs. Hawkins and Wightman's process of rounding the corner of the curve, besides being arbitrary, places the distance to which the rounding is to extend on a false basis, in expressing it as a fraction of the pole angle—of which it is quite independent. The distance in question should be expressed as a fraction of the length of the air-gap, and this fraction may be practically taken as unity, for Fig. 3 shows that at this distance under the pole the force has reached 99 per cent. of its greatest value.

Although, as above stated, the exact solution, in an actual case, is impossible, we may use the curve in Fig. 3 to correct the results of an approximate calculation, and so obtain results that are probably not greatly in error, in the following manner. Calculate the force in the usual way, *i.e.*, assume it constant under the pole, and inversely as $\xi x + g$ outside the pole, then multiply the results so obtained for any point by the ratio of the ordinate of the exact to that of the approximate curve in Fig. 3, at that point; or calling this ratio m, the force under the pole is proportional to $\frac{m}{g}$, and outside the pole to $\frac{m}{\xi x + g}$. A table of the values of m at different distances (x) from the pole tip is given below. (Table II.)

TABLE II.

x/g	−1	−0·75	−0·5	−0·25	0	0·25	0·5	0·75	1	1·5	2	3	4	6	8	10	12
m	0·09	0·073	0·052	0·91	0·84	1·04	1·14	1·20	1·22	1·21	1·20	1·18	1·16	1·13	1·09	1·05	1·01

In Fig. 3 is also shown the curve of total flux, to such a scale that the difference of ordinates at any two points gives the number of spaces equal to the air-gap that would be filled by the lines if they were concentrated to their maximum density. Thus the total flux from $x = -1{\cdot}71\,g$ to $x = 8g$ would fill $3{\cdot}54g$ with lines at maximum density, and if the lines had their maximum density throughout, the pole-piece would have to be widened by $(3{\cdot}54 - 1{\cdot}71) = 1{\cdot}83$ times the length of the air-gap. From this we get the permeance of the air-gap. This, however, neglects the effect of the adjacent pole, which causes the force to diminish to zero at the middle of the interpolar space. We might approxi-

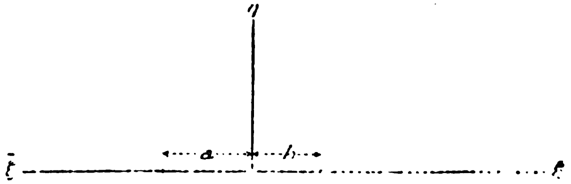


FIG. 4.—The Plane of $\xi\eta$.

mately take this into account by drawing the curves for the two poles, and adding their ordinates algebraically. This, however, is not a true solution of the problem presented by the two poles, and it would be well to examine how nearly it can be relied upon. As a matter of fact, it is possible to get an exact solution of the magnetic problem presented by two unlike rectangular poles and a straight armature, as follows :—

The transformation

$$z = \frac{g}{\pi} \log \left[\zeta + \frac{a-b}{2} + \sqrt{\zeta + a\zeta - b}\right]$$
$$- \frac{c}{\pi} \sin^{-1}\left[\frac{2ab}{a+b\zeta} - \frac{a-b}{a+b}\right]$$

(where c is a half of the distance between the poles $= g\sqrt{\frac{a}{b}}$ and the other letters are as before),

converts the half-plane, [illegible] into the region, Fig. 5,

bounded by a pole-piece, armature, and the median line between the pole pieces, making the range of points $\bar{\xi}$ A O B ξ in Fig. 4 into those so marked in Fig. 5. If now we find a potential function which reduces to ϕ_0 on the pole-piece, and to zero on the armature and median line, we shall have solved the problem in hand. Such a function is given by

$$\zeta = e^{i\pi\frac{\phi + i\psi}{\phi_0}}$$

Substituting for ζ as before, and putting $\phi = o, \pi\frac{\psi}{\phi_0} = X$ we get

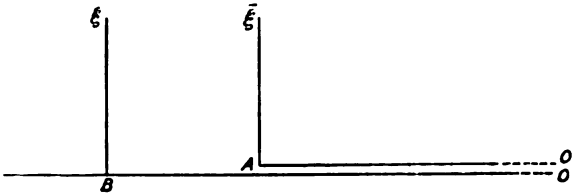


Fig. 5.—The Plane of $x\,y$.

$$\left\{\begin{array}{l} x = \frac{g}{\pi}\log\left[e^{-X} + \frac{a-b}{2} + \sqrt{(e^{-X}+a)(e^{-X}-b)}\right] \\ \quad - \frac{c}{\pi}\sin^{-1}\left(\frac{2\,a\,b}{a+b}e^{X} - \frac{a-b}{a+b}\right) \quad \ldots\ldots\ldots \quad \text{iii} \\ F = F_0\left(\frac{e^{-X}-b}{e^{-X}+a}\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots \quad \text{iv} \end{array}\right.$$

The origin in Fig. 5 is not yet determined. If we choose a and b so that

$$a + b = 2\,e^{-\frac{\pi c}{2 g}}$$

i.e. (since $\frac{a}{b} = \frac{c^2}{g^2}$), $a = \frac{2\,c^2}{c^2+g^2}e^{-\frac{\pi c}{2g}}$, $b = \frac{2g^2}{c^2+g^2}e^{-\frac{\pi c}{2g}}$,

we shall make $x = o$ at the edge of the pole-piece.

Fig. 6 shows the relation between F and x obtained from these formulæ (iii and iv), in three cases, viz., for $c = 2{\cdot}5g$, $c = 5g$, and $c = \infty$, the latter being the same curve

as in Fig. 3. It will be seen that the second pole-piece has practically no effect at point under the first, thus showing that the process of superposing the effects of two such isolated poles as shown in Fig. 3 would lead to results far from the truth; in fact, the closeness of the curves at their upper bend is their most noticeable feature. The curves for any other particular value of the ratio c/g can easily be traced from the above formulæ, though, if the curve $c = \infty$ be traced from Table I., the deviation therefrom might almost be drawn freehand with sufficient accuracy, after an

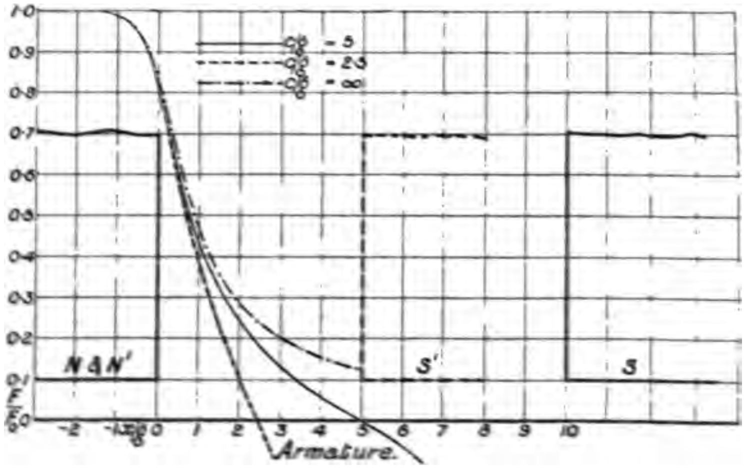


Fig. 6.

examination of Fig. 6. The slope of the curve where it cuts the armature is:

$$\frac{g}{F_0}\frac{dF}{dx} = \frac{\pi}{2} \cdot \frac{1}{\frac{c^2}{g^2} + 1}.$$

The permeance of the air-gap can now be obtained exactly. If we determine the total flux, up to $x = c$, *i.e.*, to half-way between the poles, and find what width we must add to the pole face to give the total flux this value, supposing the force to have its maximum value F_0, throughout the region underneath this increased pole, and to be zero elsewhere, then, expressing this in the usual manner, *i.e.*, as a

fraction (λ) of the length of the air-gap, we shall find that λ is not a constant, as usually assumed, but is given by

$$\lambda = 0{\cdot}72 \log \left\{ \frac{1}{4} \left(1 + \frac{c^2}{g^2}\right) \right\} + \frac{1}{90} \left(\frac{c}{g} \tan^{-1} \frac{g}{c} \right),$$

where the logarithm is a common one, and the angle is expressed in degrees.

Table III. gives the value of λ for the different values of c/g within the possible limits in this subject.

TABLE III.

c/g	2	2·5	3	3·5	4	4·5	5	6	7	8	9	10	11	29
λ	0·68	0·79	0·90	0·99	1·07	1·15	1·22	1·33	1·42	1·51	1·58	1·65	1·70	..

The value of these calculations is well seen by comparing the values of λ in the above with those given by the usually assumed methods. Thus Messrs. Hawkins and Wightman obtain $\lambda = 1{\cdot}76$ for $c/g = 4$,[1] whilst the more nearly correct calculation gives the much smaller value $\lambda = 1{\cdot}07$; in fact, formulæ based on simple but wrong assumptions are dangerous things to use, and can rarely be relied on to give more than the order of the sought-for results.

I by no means recommend that one should go to the trouble of using these somewhat difficult formulæ in average practical cases, for they of course only apply strictly to the ideal cases considered, but submit that the reasons given at the beginning of this article are sufficient justification for placing on record the solution of a problem which more nearly resembles the actual problem of the fringe of lines in the interpolar space than any which has, as far as I am aware, been exactly worked out.

THE RELUCTANCE OF THE TEETH IN A SLOTTED ARMATURE.

By W. B. HIRD, B.A., Member.

In predetermining the characteristic of a dynamo with slotted armature the calculation of the ampere-turns required

[1] Page 449.

to pass a given number of lines through the teeth is a matter of some difficulty.

A considerable error in this quantity is, however, usually only a small percentage on the total ampere-turns required for the whole machine, and, moreover, most of the usual methods err on the safe side by giving too high a value for the ampere-turns required.

If, however, the same methods are used to calculate the effect of the teeth reluctance on the cross field, and thus to obtain a value for the residual field under the weakened magnet tip, the errors become of importance in the final result, and, moreover, they are now not on the safe side, but lead to a value of residual field larger than the correct one. The following method, while only an approximation, is not too cumbersome for practical use: it gives results which are more nearly correct than those obtained by calculating the value of H at only a few sections of the teeth and taking the mean, and it is less tedious than taking values at a large number of such sections.

From the (H B) curve of the iron used plot a second curve with B as ordinates and $\int_{B_0}^{B_1} H.dB$ as abscissæ, any convenient value being taken for B_0. Then in any given case calculate the induction (say B_1) at the top of the tooth and B_2 at the bottom, on the assumption that the whole of the lines pass through the tooth: the values of $\int H dB$ when $B=B_1$ and when $B=B_2$ can be read off the curve, call these values α_1 and α_2 respectively, the mean value of H throughout the tooth will then be $\dfrac{\alpha_2-\alpha_1}{B_2-B_1}$ and from this the ampere-turns are directly calculable.

It is convenient that B_1 and B_2 should be greater than B_0: that is in integrating the H B curve, B_0 should be chosen smaller than any value of B for which the curve is to be used.

An approximate correction can be made for the fact that the lines leak into the slot and do not all pass through the tooth, as follows:—

Let c be the width of tooth at the bottom, and a the width of slot. It is generally only at the bottom of the tooth where the inductions are high that the leakage into the slot

becomes of importance. Let the real induction at the bottom of the tooth be B_3 and let H_3 be the corresponding value of H; then

$$c\,B_3 + a\,H_3 = c\,B_2$$

$$\therefore B_3 + \frac{a}{c}\,H_3 = B_2,$$

B_2 being, as before, the value of the induction calculated on the assumption that the whole of the lines pass through the tooth. Instead, therefore, of integrating the (H B) curve of the iron, first plot from it a curve with H as abscissæ and $B + \frac{a}{c}H$ as ordinates. Call this curve the (H B) curve for this particular tooth; integrate this curve and proceed exactly as above.

It is of course not possible in practice to do this for all

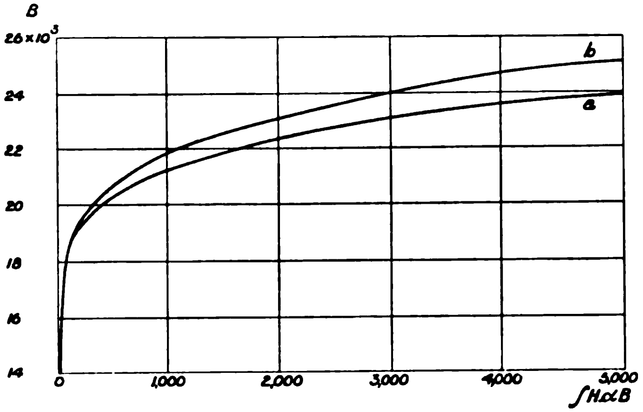


FIG. 1.

values of the ratio $\frac{a}{c}$, but we can choose two or three convenient values of $\frac{a}{c}$ and plot corrected curves for these values. In any given case we can use the nearest curve without any serious error, as the ratio $\frac{a}{c}$ does not usually vary very largely in different machines of the same type.

The curves (Fig. 1.) have been in practical use for some considerable time with satisfactory results; (*a*) is plotted as described from the (H B) curve for soft charcoal iron, and (*b*) is corrected on the assumption that $\frac{a}{c} = 1$.

In the above the assumption is made that the induction varies uniformly between the values B_2 and B_T; this of course is not strictly true, it is the area of the tooth which varies uniformly between c and b, and the induction is the reciprocal of this. The following is a stricter method, the only assumption made being that in any one tooth and slot the equipotential surfaces are cylindrical and coaxial with the armature.

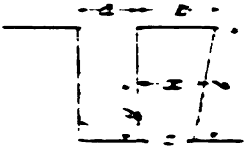


Fig. 2

Let a = width of slot (see Fig. 2).
b = " of tooth at top.
c = " " " " root.
l = depth of slot.
y = distance measured from bottom of slot.
x = width of tooth at point y.
B = induction at point y.
H = magnetic force " y
and N = total No. of lines per tooth per unit length of armature.

The ampere-turns required on the teeth are proportional to the line integral of H; we therefore want to find the value of $\int_0^l H\,dy$.

We have $x = c + (b - c)\dfrac{y}{l}$ $\therefore$ $\dfrac{dx}{dy} = \dfrac{b-c}{l}$

and
$$\int_0^l H\,.\,dy = \int_c^b H\,\frac{dy}{dx}\,.\,dx$$

$$= \frac{l}{b-c}\int_c^b H\,.\,dx. \quad \ldots \ldots \ldots \quad \text{I.}$$

Again
$$a\,H + x\,B = N.$$

$$\therefore x = \frac{N}{B} - \frac{a\,H}{B}$$

$$\therefore \frac{dx}{dB} = -\frac{N}{B^2} - a\,\frac{d\left(\frac{H}{B}\right)}{dB}$$

$$\therefore \text{from (I.)} \int_0^l \mathrm{H}\,.\,d\,y = -\frac{l}{b-c}\left\{\mathrm{N}\int_{\beta_2}^{\beta_1}\frac{\mathrm{H}}{\mathrm{B}_2}\,d\,\mathrm{B} + a\int_{\beta_2}^{\beta_1}\mathrm{H}\,.\,d\left(\frac{\mathrm{H}}{\mathrm{B}}\right)\right\}$$

$$= \frac{a\,l}{b-c}\left\{\mathrm{N}\int_{\beta_2}^{\beta_1}\frac{\mathrm{H}}{a}\,d\left(\frac{1}{\mathrm{B}}\right) - \int_{\beta_2}^{\beta_1}\mathrm{H}\,d\left(\frac{\mathrm{H}}{\mathrm{B}}\right)\right\} \quad . \quad . \quad \mathrm{II}.$$

From the known H B curve of the iron used we can plot once for all curves having B as abscissæ and $\int \mathrm{H}\,d\left(\frac{1}{\mathrm{B}}\right)$ and $\int \mathrm{H}\,d\left(\frac{\mathrm{H}}{\mathrm{B}}\right)$ respectively as ordinates; and the values corresponding to β_1 and β_2 read off these curves give us as at once by substitution in II. the line integral of H for the tooth, and consequently the ampere-turns required.

In order to find the proper values of β_1 and β_2 we have

$$x = \frac{\mathrm{N}}{\mathrm{B}} - \frac{a\,\mathrm{H}}{\mathrm{B}}$$

$$= a\left\{\frac{\mathrm{N}}{a}\cdot\frac{1}{\mathrm{B}} - \frac{\mathrm{H}}{\mathrm{B}}\right\} \quad . \quad . \quad . \quad . \quad . \quad \mathrm{III}.$$

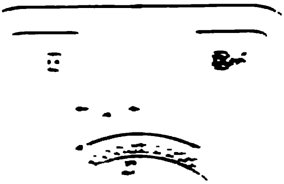
From the original (H B) curve plot two more curves with B as abcissæ and $\frac{1}{\mathrm{B}}$ and $\frac{\mathrm{H}}{\mathrm{B}}$ respectively as ordinates; we can find on these curves two values of B which when substituted in III. will make x equal first to b and then to c; these values are B_1 and B_2 respectively.

This process is evidently too cumbersome for everyday use, but the writer has seen an ingenious model due to Mr. C. McMillan, B.Sc., which being set to the two constants $\frac{a\,l}{b-c}$ and $\frac{\mathrm{N}}{a}$ gives, by the simultaneous motion of four templates carrying the four curves above mentioned, direct readings of the ampere-turns required; a description of this instrument is, he understands, to be shortly published by Mr. McMillan.

It has been already pointed out that it is when the influence of the teeth reluctance on the cross field is in

question that these results are of the greatest importance. It is also important to notice the effect of the tooth reluctance on the total number of lines entering the armature with a given number of cross-turns under the pole face. In a smooth-core armature the total flux entering the armature under one pole face is independent of the cross-turns under the pole, and it is often assumed that the same holds good for slotted armatures; this, however, is not generally correct.

Let Fig. [illegible] represent half the magnetic circuit of a dynamo, with a ampere-turns on each limb and [illegible] ampere-turns under the pole. Assume the reluctance of the gap between armature core and pole face to be large compared with that of the rest of the circuit so that the ampere-turns a may be considered as all acting on the gap.



[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[redacted]

This will be independent of c if and only if

$$\frac{dN}{dc} = o$$

but

$$\frac{dN}{dc} = \int_{-l}^{l} \frac{d f\left(A + \frac{x}{l} c\right)}{dc} \, dx$$

$$= \int_{-l}^{l} f'\left(A + \frac{x}{l} c\right) \frac{x}{l} \, dx$$

Expand $f'\ (A + \frac{x}{l} c)$ in ascending powers of x and let $f'\ (A + \frac{x}{l} c) = K_o + K_1 x + K_2 x^2 + K_3 x^3 +$ etc. Then $\frac{dN}{dc} = o$ if $K_1\ K_3$ and all the coefficients of odd powers of x are each $= o$, *i.e.*, if $f'\ (A + \frac{x}{l} c) = K_o + K_2 x^2 + K_4 x^4 +$ etc.,

$$\text{but } f'\left(A + \frac{x}{l} c\right) = \frac{d f\left(A + \frac{x}{l} c\right)}{dx} \cdot \frac{dx}{d\left(A + \frac{x}{l} c\right)}$$

$$= \frac{d f\left(A + \frac{x}{l} c\right)}{dx} \cdot \frac{l}{c}$$

$$\therefore f\left(A + \frac{c}{l} x\right) = \frac{c}{l} \int f'\left(A + \frac{c}{l} x\right) dx$$

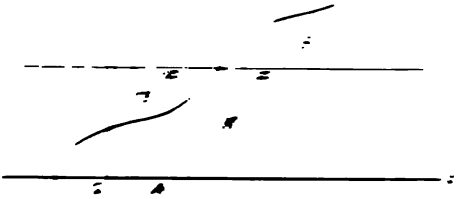
Substitute the value of $f'\left(A + \frac{c}{l} x\right)$ obtained above, and

$$f\left(A + \frac{c}{l} x\right) = K + K_o x + \frac{K_2}{3} x^3 + \frac{K_4}{5} x^5 + \text{etc.} \qquad \text{IV.}$$

is the necessary condition for the total flux, being independent of the cross-turns; but if $A + \frac{c}{l} x$ represent the ampere-turns at any point $f\left(A + \frac{c}{l} x\right)$ represents the corresponding induction.

[illegible]

[illegible]



[illegible] given [illegible] the sum of these [illegible] will be repeated but with the [illegible] sign by changing the sign of [illegible] that is the curve [illegible] have that symmetry about the straight line [illegible] which is shown in figure [illegible]

That the magnetisation curve of the gap should possess this symmetry is the necessary condition in order that the total number of lines should be independent of the cross-turns.

If the gap between magnet and armature core is uniform, the magnetisation curve is a straight line passing through [illegible] and possesses the necessary symmetry; therefore in the case of a smooth-core armature the total flux is unaltered by the cross-turns.

This result can be obtained directly from equation IV., for suppose K_2, K_4 and all coefficient except K_o vanish,

$$\therefore f\left(A + \frac{c}{l} x\right) = K + K_o x,$$

which will give a straight line on our diagram.

If, however, there is iron in the gap, such as the teeth of a slotted armature, we can see from our knowledge of the (H B) curve of iron that there is only one case in which the magnetisation curve has the necessary symmetry, that is when the point (A K) coincides with the point $H=o$ $B=o$ of the iron curve. The physical meaning of this is obvious; if there are no ampere-turns on the magnets the total flux into the armature is *o*, and will remain *o* independently of whatever cross-turns there may be. Under no other condition can the true magnetisation curve have the required symmetry, and therefore under no other conditions will the total flux into the armature be independent of the cross-turns.

The condition thus obtained analytically is fairly obvious from the purely physical conditions of the problem; only if the increased induction due to an increase of ampere-turns is exactly counterbalanced by an equal decrease in the induction due to an equal decrease in ampere-turns can the reluctance of the gap remain a constant with different distributions of induction under the pole.

The above treatment does not indicate the amount by which the total flux may be varied by given values of the cross-turns, but as a matter of experiment this value, when the teeth are worked at high inductions, is far from negligible in practice, and must be allowed for specially in the case of large machines.

ON THE ABSOLUTE VALUES OF CAPACITY MEASUREMENTS.

By J. ELTON YOUNG, Member.

In the discussion of my paper on "Capacity Measurements of Long Submarine Cables" at the Institution last May (*vide* Journal, vol. xxviii. pp. 475 *et seq.*), some un-

[illegible]

[illegible] particular value [illegible] when balanced against the [illegible] standard after the same time of charge as that used in

balancing it against the cable, and employing this value in the ordinary Gott or Thomson measurement of the cable (see p. 480 of paper). But this system, by leading to a variety of results dependent on the time of charging, would tend to complicate instead of simplifying tests.

Hence it is that the method recommended, under the title of the "modified Thomson," has been found the best plan for securing uniformity of measurement, notwithstanding that it yields neither the surface nor the total capacity absolutely. It would furnish the former were it not that it involves the discharging and mixing of residual charges. Nor does it determine the latter strictly, because allowance is not made for the variation of the condenser value with time in connection with this mixing of the charges.

I do not think it is necessary to reduce our measurements to their absolute values, since they are all derived from paraffin condensers. But it is therefore desirable to adhere to the uniform mode of observation recommended, alike in the factory and after submersion, thus fixing the datum for localisations of insulated breaks or cuts.

Since it appears that at least three other tests for inductive capacity originated with Lord Kelvin, I think that, as Mr. Charles Bright suggested, a more distinctive title than the "modified Thomson" might be given to the method in question. I accordingly propose to call it Murphy's, his right to be associated with it being certainly greater than that of any one else.

The other questions raised during the discussion of the subject related mainly to the "effective" capacity of submarine cables for signalling, a matter of the greatest interest, but beyond the scope of this communication. We are indebted to Mr. Charles Bright for laying special stress on this in his important contribution to the telegraphic debate at the Institution last May; and I should like, in conclusion, to express my regret that his remarks received so little notice in the reply made on my behalf by Mr. Murphy. It is due to Mr. Bright to say that his criticisms were substantially accepted by me, and that I can endorse his views, with the exception of the idea, which seems to have prevailed generally, as to the actual results of cable capacity tests.

Institution of Electrical Engineers.

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1. *Creation of a Local Section.*—The Petition or Request to the Council prescribed by Article No. 65 of the Articles of Association as a necessary preliminary to the creation of a Local Section, shall be signed by at least 50 persons, of whom ten shall be Members or Associate Members of the Institution of Electrical Engineers or persons qualified to belong to one of these classes.
2. *Membership.*—The Membership of any Local Section shall consist of persons who are members of any class of the Institution of Electrical Engineers, and whose residence or occupation is within a reasonable distance of such Local Centre.
3. *Subscriptions.*—No special subscription shall be required from members of a Local Section, in addition to those payable to the Institution of Electrical Engineers in the ordinary course in accordance with the Articles of Association.
4. *Expenses.*—The necessary ordinary expenses of a Local Section shall be borne by the Institution, subject to a limit, in the form of a grant, which shall be fixed annually by the Council in advance.
5. *Management of the Section.*—The affairs of each Local Section shall be managed by a Committee consisting of a Chairman, Vice-chairman, and Honorary Secretary, and not fewer than six members of whom the Chairman shall be a Member, and the Vice-chairman a Member, Associate Member or Associate of the Institution of Electrical Engineers.
6. *Hon. Secretaryship of Section.*—An Honorary Secretary of the Section shall be elected by the Committee, and shall be of any rank in the Institution above that of Student.
7. *Election of Officers and Council.*—The mode and time of election of the Officers and Committee shall be as nearly as possible the same as the mode and time of election of the Officers and Council of the Institution of Electrical Engineers, but the same Chairman and Vice-chairman shall not hold their respective offices for two years in succession, and no one, except the Honorary Secretary, shall remain a member of the Committee in the same capacity for more than three years consecutively.
8. *Representation on Council of the Institution.*—The Chairman of each Local Section shall, in accordance with the Articles of Association, be *ex-officio*, and during his year of office, a Member of the Council of the Institution.
9. *Work of the Committee.*—The Committee shall arrange and manage all the affairs of the Section, in conformity, so far as is possible, with the practice of the Institution.

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11. *Publication of Papers.*—Every paper or communication read at a meeting of a Local Section shall be the property of the Institution, which shall have a prior right to publish it in the Journal, but if that right be not exercised within a reasonable time the writer shall be at liberty to publish it in any way he likes.

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13. *Premiums.*—Papers read at Local Sections and published in the Journal of the Institution shall, for the purpose of award of premiums, be deemed to have been read at an Ordinary General Meeting of the Institution.

14. *Dates of Meetings.*—The dates of meetings of a Local Section shall be fixed by the Committee, and shall be announced at the beginning of the Session.

15. *Bye-laws.*—Each Local Section shall be at liberty to prescribe its own Bye-laws.

16. *Records.*—A copy of every document or paper printed or issued by the Committee of any Local Section shall be forwarded to the Secretary of the Institution for record by the Institution.

Institution of Electrical Engineers.

GENERAL RULES RELATING TO THE CONSTITUTION AND MANAGEMENT OF LOCAL SECTIONS BEYOND THE LIMITS OF THE UNITED KINGDOM.

1. *Petition for a Local Section beyond the limits of the United Kingdom.*—The Petition or Request to the Council prescribed by Article No. [illegible] of the Articles of Association as a necessary preliminary to the creation of a Local Section shall be signed by a sufficient number of members of any class or classes in the Institution of Electrical Engineers to satisfy the Council that the movement has behind it an adequate amount of local support and that it is representative of Electrical Engineering in the Colony or Province submitting the petition.

2. *Membership.*—The membership of any Local Section shall consist of persons who are members of any class of the Institution of Electrical Engineers and whose residence or occupation is within a reasonable distance of such Local Centre.

3. *Subscription.*—Each member of a Local Section in addition to his ordinary subscription as a non-resident member of the Institution payable to the Institution in the ordinary way shall pay to that Local Section such amount annually as the said Local Section may from time to time prescribe in its rules.

4. *Expenses.*—Each Local Section shall be responsible for the expenses of that Section and shall administer at its own discretion the the amounts levied for local purposes under Rule 3.

5. *Management of the Section.*—The affairs of each Local Section shall be managed by a Committee consisting of a Chairman, Vice-Chairman, and Honorary Secretary, and not fewer than four members, of whom the Chairman shall be a Member and the Vice-Chairman a Member, Associate Member or Associate of the Institution of Electrical Engineers.

6. *Hon. Secretaryship of the Section.*—An Honorary Secretary of the Section shall be elected by the Committee and shall be of any rank in the Institution above that of Student.

7. *Election of Officers.*—The mode and time of election of the Officers and the Council shall be as nearly as possible the same as laid down in Articles numbered 43, 44, 45 and 57 of the Articles of Association of the Institution of Electrical Engineers for the mode and time of election of Officers and Council of the Institution, subject to the provision that the Honorary Secretary may remain in office for a longer period than three years.

8. *Representation on Council of Institution.*—The Chairman of each Local Section shall, in accordance with the Articles of Association, be *ex-officio* and during his term of office a member of Council of the Institution.

9. *Work of the Committee.*—The Committee of any Local Section shall arrange and manage all the affairs of the Section, in conformity, so far as is possible, with the practice of the Institution.

10. *Communications to the Local Section.*—The Committee of a Local Section shall be the authority for the acceptance or rejection of papers or communications to be read at the meetings of such Local Section.

11. *Publication of Papers.*—Every paper or communication read at a meeting of a Local Section shall be the property of the Institution, which shall have a prior right to publish it in the Journal, but if that right be not exercised within a reasonable time the writer shall be at liberty to publish it in any way he likes.

12. *Publication of Discussions.*—Permission for the publication of any report of the discussion at a Local Section shall rest with the Committee of the Local Section.

13. *Premiums.*—Papers read at Local Sections, if considered by the Council worthy of publication in the Journal of the Institution, shall, for the purpose of the award of Premiums, be deemed to have been read at an Ordinary General Meeting of the Institution.

14. *Dates of Meetings.*—The dates of meetings of a Local Section shall be fixed by the Committee and shall be announced at the beginning of the Session.

15. *Bye-Laws.*—Each Local Section shall be at liberty to prescribe its own Bye-Laws.

16. *Records.*—A copy of every document or paper printed or issued by the Committee of any Local Section shall be forwarded to the Secretary of the Institution for record by the Institution.

OBITUARY NOTICES.

MORGAN MARK BEVAN, born 21st March, 1840, died 12th October, 1899. Mr. Bevan had seen considerable service in various capacities in both hemispheres. From 1874 to 1876, he was with the Western and Brazilian Telegraph Company as Superintendent at their stations of Santa Catharina and Rio de Janeiro. From 1879 to 1883, and again later he served with Messrs. Siemens Bros. and Co., as electrician in the testing of submarine cables during manufacture, laying and repair. From 1883 to 1887, he acted as electrician in the torpedo division attached to the Argentine and Chilian Governments. He was afterwards employed in superintending the manufacture and laying of submarine cables in the West Indies, and from 1887 to 1899 he was engaged in electrical, mechanical and other testing work at the Postal Telegraph Factory, Mount Pleasant, London.

He was elected a Member of this Institution on the 22nd of May, 1890.

J. G.

THOMAS BUCKNEY was born December the 1st, 1838, and died, after a short illness, February 1st, 1900.

He was for many years head of the old established firm of E. Dent & Co., who are chronometer, watch and clock makers to Her Majesty and H.R.H. the Prince of Wales, and who were makers of the great clock of the Houses of Parliament. One of their establishments in Hanway Place is a factory for making turret and other clocks, as well as Patent Marine Compasses and other scientific instruments.

Mr. Buckney took a prominent part in designing the Standard Sidereal Clock at Greenwich Observatory, also the Galvanic Chronographs at the Brussels and Japan Observatories. He took an active part in arranging clocks for recording the transit of Venus in 1872. He also designed galvanic contact-work for ships' chronometers. One of his latest works was designing and constructing the new great clock for the cathedral at Gloucester.

Mr. Buckney read a paper in January, 1880, before the Royal Astronomical Society, of which he was a Fellow, on a proposed new Uniform Pressure Clock.

He was a Member of the Clockmakers' Company, the Institutions of Electrical and Mechanical Engineers, the Society of Arts, and the Committee appointed by the British Association for the purpose of determining a universal gauge for the dimensions and pitches of screws employed in electrical and other apparatus.

He was elected a Member of this Institution on the 18th of January, 1883.

A. S.

MATTHEW COOPER.—By the death of Mr. Matthew Cooper the Institution has lost one of its earlier members. The deceased gentleman was found dead in a train at Finsbury Park station on his way to the City on the morning of Thursday, March 8th. He originally entered the service of the Electric and International Telegraph Company in

1861, and was transferred to the Postal Telegraph Service in 1870, when the various Telegraph Companies in the United Kingdom were acquired by the State. From that time until 1878, Mr. Cooper was engaged in a branch which was organised to deal with special events arising throughout the country, and in that capacity he took charge of the telegraphs at Sandringham when the Prince of Wales was in residence.

Subsequent to the year 1878, Mr. Cooper was attached to the staff of the Engineer-in-chief, and at the time of his death he held the position of Principal Technical Officer. He was associated with the development of the various systems of telegraphy which have been brought into use in the Post Office during the past twenty years. He took an active share in improving duplex telegraphy, and subsequently the successful working of the quadruplex and multiplex systems was largely due to the untiring energy with which he devoted his extensive knowledge of details and his mechanical skill to their development. Since the introduction of the telephone, Mr. Cooper has been associated with its extension in the Postal Service, and for some time past he had been engaged in working out details for the equipment of the telephone exchanges which are to be installed in connection with the proposed Government scheme for the telephoning of London. Mr. Cooper served as an Associate Member of Council of the Institution in the year 1892. His untimely death occurred at the comparatively early age of fifty-three.

His resourceful tact and the geniality of his disposition endeared him to all with whom he had business relations, and his loss has been much felt.

He was elected an Associate of this Institution on the 14th of April, 1880. J. G.

MONTAGU CHARLES DENT received his education from 1885 to 1889 at Eton, and at King's College, London, from 1890 to 1891. He served his time with Messrs. Robey and Co., Lincoln, from 1892 to 1894, and also at the works of the Brush Electrical Engineering Company, Limited, Loughborough, Leicestershire, from 1894 to 1896.

During 1896 and part of 1897 he was employed on installation work at Arundel Castle, on central station work at the Wandsworth electric light station, and in the erection of the exhibition plant at the Earl's Court Exhibition. On October 1st, 1898, he joined Mr. Reginald J. Wallis-Jones in partnership as consulting engineers in Westminster, and carried out several important installations of electric light and power plants. He died at the age of 27, on June 28th, 1890, after a very short illness subsequent to an internal operation.

He was elected an Associate of this Institution on the 15th of December, 1898, and was transferred to the class of Associate Members on the 9th of February, 1899. R. S. W.

JAMES DRUMMOND DOYLE, who died at the age of forty-four, on the 7th of December, 1899, was the son of a well-known Australian journalist. He commenced his life's work at the age of thirteen in the Department of Railways in Victoria. Having matriculated at the

University at the same age, he continued his studies whilst still engaged in official work, with a view to joining the legal profession. In the end, however, he decided not to sever his connection with the railway, and whilst still quite young became manager of the chief railway telegraph office in Melbourne. In 1891 the offices of Telegraph and Traffic Inspector were united, and Mr. Doyle, at his own request, obtained the position of Chief Clerk in the Locomotive Branch, which necessitated less travelling than would devolve upon the holder of the joint inspectorship. He acted for a time as one of the electricians of the Naval Torpedo School in Melbourne, and was a member of several important commissions. His energy, ability, and conscientious work earned for him the confidence and respect of his Department, and his personal character endeared him to those with whom he was brought in contact.

Mr. Doyle was elected an Associate of this Institution, then the Society of Telegraph Engineers, on the 12th of December, 1877, and was transferred to the class of Members on the 24th of November, 1881.

LUDWIG EPSTEIN was an Austrian by nationality, being the only son of a banker at Teplitz in Bohemia, a well-known health resort. He was born in 1853, and was consequently only forty-six years of age at the time of his death in August, 1899.

His father, recognising the liking of his son for physical research, provided him with a laboratory, and at the early age of seventeen he was busy preparing himself for the study of accumulators, the improvement and application of which were his sole object for nearly twenty-five years.

In 1879 he came to England and carried on a series of experiments at the works of the Pilsen Joel Company. During nearly three years' stay in England he progressed so far that he returned to the Continent and commenced manufacture at Leipzig. A misfortune befell his business there by the occurrence of a series of short circuits on a temporary installation in the Gewandhaus on the occasion of a royal visit. His accumulators, which were being used to provide the current, were in no way to blame, but the prejudice created by the mishap was too great to overcome. Moving to Berlin his accumulator was taken up by the firm of Siemens and Halske, and Mr. Epstein became the director of the accumulator department of that firm. He married in 1886. In 1889 he became seriously affected by lead poisoning, and during his convalescence he took the opportunity to reconsider the whole question of accumulator manufacture. Up to that time he had adhered to the pasted grid system of making plates; thenceforward he became the apostle of the modified Planté.

In 1890 he brought his new plates to London, and after undergoing severe tests they were taken up by Woodhouse and Rawson, Limited, and a year later the Epstein Company was formed.

The results obtained showed that a great step in advance had been made, and the Epstein cells rapidly came into favour on account of their freedom from most of the weaknesses long associated with accumulators.

Mr. Epstein soon attacked the problem of accumulator traction,

though the figures obtained during a two years' trial on a section of the Birmingham tramways were not encouraging to the cause in England; but, as was acknowledged afterwards in the discussion of a paper on the subject of electric traction at the Institution of Electrical Engineers by Mr. Epstein, the fault lay not with the accumulators but with the installation of the system.

Mr. Epstein had set himself a high ideal for an accumulator, and towards this he continued to press. Experiments were constantly carried on in his private laboratory at Richmond. The application of accumulators to launches, torpedoes, and traction work generally occupied the whole of his time, and to the last he was at work on an improved form of traction cell. His early death was caused by the worry of litigation affecting an impetuous mind concentrated upon arriving at perfection. His great experience of accumulators made him a valuable authority on the subject, and though an enthusiast in his special line he always recognised the limitations of the lead accumulator, and was ready to try any substitute which showed promise of success.

He was a great admirer of all things English; if he had lived he had intended to become a naturalised British subject. He leaves a widow and one boy.

He became an Associate of the Institution on the 24th of November, 1892, and was transferred to the class of Members on the 25th of February, 1897. His paper on "Accumulator Traction on Rails and Ordinary Roads" was read at the Ordinary General Meeting on the 11th of November, 1897.

W. S. R.

DAVID EDWARD HUGHES, F.R.S.—On the 22nd of January in the present year death deprived the world of Science and this Institution of one of the most brilliant experimental discoverers and inventors of the century; and at the same time a large circle of friends lost one of their number whom they loved and greatly admired.

David Edward Hughes was a Welshman by parentage, a Londoner by birth, and for some twenty years an American by adoption, returning in 1857 to this country, where he settled and remained until his death. Born in London on the 16th of May, 1830, he, with his parents, migrated to Virginia when he was barely seven years old. From a very early age the boy displayed a remarkable talent for music, and this developed to such an extent that at the age of nineteen he was appointed Professor of Music in the Bardstown College in Kentucky; but side by side with his love of music was, at the same time, developing a love for experimental science, chiefly in the domain of Physics. After holding his musical professorship for a short time he was appointed to the Chair of Natural Philosophy in the same college, and for a time taught both Music and Physics. It was during this period that he first conceived the idea of the Printing Telegraph with which his name must ever be associated. The Hughes Type Printer is so well known to the readers of this Journal that it would be superfluous to describe it; but one of its essential characteristics is the wonderfully

[illegible] railway signalling [illegible] Electric Telegraph Company [illegible]

[illegible] Belgium. [illegible] Western [illegible] United States. [illegible] Professor [illegible]

[illegible]

gallipots and lamp chimneys, copper bell wire, sheet zinc and pipe-clay, and it was always the delight and admiration of all who had the privilege of seeing him at work to observe the spirit of the true philosopher who, with such apparently rough apparatus, attained such accurate and important results.

In the month of May, 1878, a few friends assembled at his rooms in Great Portland Street to witness some demonstrations of what was then thought to be the discovery by Professor Hughes of "a material which bore an analogous relation to sound that selenium bore to light," but which was the first demonstration of the epoch-making Microphone; this little gathering consisted of the late Professor Huxley, Mr. (now Sir) William Preece, Mr. (now Sir) Norman Lockyer, Mr. Conrad Cooke, and Mr. Perry Nursey. The experiments were repeated at the Meeting of the Royal Society in the following week; and an illustrated description, in which the now accepted theory of the action of the Microphone was given for the first time, appeared in the columns of *Engineering* the next day.

It is not too much to say that, but for the discovery by Professor Hughes of the variation of electrical resistance by the variation of surface contact between two or more conductors touching lightly together in exact proportion to sonorous waves impinging upon thém, whereby they are set into sympathetic vibration, the telephone could never have been made the practical instrument that we know to-day; and although Professor Hughes fully appreciated the future there was before the microphone, he refused all suggestions of converting it to commercial use for his own benefit, and gave the invention and discovery freely to the world as the true man of Science that he was.

The microphone was almost immediately followed by his Induction Balance, by which the presence of an inductive mass may be detected at a distance, and it will be within the memory of many who read this notice that it was successfully applied to locating the bullet in the body of President Garfield, who died by the hand of an assassin in the year 1881. It is also applicable to the tracing of metallic ores in the earth, and, by a simple modification, it becomes an instrument for measuring the sensitiveness of the sense of hearing.

The subject of transmitting telegraphic signals from one station to another without a metallic conductor between them engaged the attention of Professor Hughes between 1879 and 1886, and there is no doubt that he discovered at that time the fact that poor conductors, such as finely-divided metals or carbon, become good conductors under the influence of electric waves, a discovery which was subsequently made by M. Branly, and which we now know as the phenomenon of cohesion by the impact of etheric or Hertzian waves. With such a coherer, Professor Hughes, some twenty years ago, in the presence of Professor Huxley, Professor Stokes, and Mr. Spottiswoode (then President of the Royal Society), transmitted electric signals without connecting wires to a distance of five hundred yards, and attributed the action of the combination to the results of electric waves produced by the extra current from an induction coil beating upon a microphone consisting of a semi-metallic powder.

Professor Hughes was elected a foreign member of this institutio then the Society of Telegraph Engineers, in November, 1872, bein transferred to the class of Members in 1879. In the following year h was elected a Member of Council; in 1882 he became a Vice-President and, in 1886, he was selected for, and unanimously elected to, the offic of President of the Society.

In addition to his Presidential Address on "Self-induction of a Electric Current in Relation to the Nature and Form of its Conductor,' he read before the Institution the following papers:—

"Experimental Researches into Means of Preventing Inductio upon Lateral Wires."

"Note on some Effects produced by the Immersion of Steel anc Iron Wire in Acidulated Water."

"The Cause of Evident Magnetism in Iron, Steel, and othe Magnetic Bodies."

"The Physical Action of the Microphone."

"Oil as an Insulator."

He also, in the Journal, published a "Communication" in referenc to Standard of Light, and, in conjunction with Sir Charles Bright, contributed the Report upon the International Exhibition of Electricity in Paris, 1881.

In the year 1880 he was elected a Fellow of the Royal Society, and five years later he received the Royal Society's Gold Medal, which was awarded "for Experimental Research in Electricity and Magnetism, and for the Invention of the Microphone, Induction Balance, and Sonometer." He was a Life Member of the Society of Arts, and two years ago he was awarded the Albert Medal of the Society for his distinguished services to the cause of Science and "in recognition of the service he has rendered to Arts, Manufactures, and Commerce by his numerous inventions in Electricity and Magnetism, especially the Printing Telegraph and the Microphone."

He was in the year 1889 elected one of the Managers of the Royal Institution, becoming Vice-President in 1891.

Professor Hughes, besides being an enthusiastic worker in Science and a great inventor, had another side to his character which will render him none the less missed in the world. He was simple in his tastes and modest as to his exceptional genius; he was one of the best and most genial of companions, with a keen sense of the ridiculous, thoroughly appreciative of fun in others, and those who were privileged to belong to the little coterie that used to meet at luncheon three times a week, first at the Horseshoe, Tottenham Court Road, afterwards at the Société Nationale Française, and ultimately at Frascati's Restaurant, will ever recall with pride and happy remembrance his genial comradeship, his merry and contagious laugh, his inexhaustible fund of information or story, and simple and lovable disposition. His memory will be revered by the world at large, but by that inner circle of his intimate friends that memory will be cherished with a loving tenderness.

C. W. C.

FRANK KING, who died on Thursday, August 3, 1899, at the age f forty-five, was one of those electrical engineers who, since 1880, have een intimately connected with works of electrical distribution and torage.

His name, associated with those of Messrs. Brougham and Taylor, ecame known in the pioneer days of town electric lighting as one of he inventors of the B.T.K. accumulator, used first at Colchester in 1882.

Soon after joining the Electric Power Storage Company in 1886 he turned his attention, not only to the improvement of accumulators, but also to the association of storage with distribution on a larger scale than had been previously attempted.

At that time the numerous failures with secondary batteries in private installations had led many to doubt if so costly though convenient an adjunct to electric lighting would succeed commercially, and it required a man of Mr. King's perseverance and ingenuity to apply the experience which these failures provided, so as to arrive at the success which is now taken for granted.

He improved the means: of fixing and insulating the plates, the prevention of short-circuiting within the cell, and of removing, replacing and connecting them. These improvements were the subject of patents of which little may now be thought, but which at the time covered valuable adaptations, the use of which had the effect of removing many of the difficulties and much of the prejudice which at first, between 1883 and 1887, existed against the use of accumulators.

While following up these minor improvements, Mr. King turned his attention to the use of accumulators on a large scale in connection with the public supply and distribution of electricity, and there is little doubt he looked forward to the time when this kind of transformation would be in universal use.

For purposes of practical application he designed a combination of apparatus and circuits whereby the charge and discharge of secondary batteries was automatically accomplished at the proper times without interruption of the charging or discharging circuits, and whereby the charging current, which was of high tension, was prevented from reaching the distributing mains.

The system which formed the subject of Mr. King's patents of 1886 and 1887 formed part of the original installation of the Chelsea Electricity Supply Company in 1889, and the whole of the apparatus was designed and installed in Chelsea (and in a part of Kensington, which was then included in the Chelsea order) by Mr. King as engineer of the Electric Power Storage Company.

In the same year it was described to a meeting of G Section of the British Association at Newcastle by Major-General Webber, who at the time was in charge of the engineering management of the Chelsea Company, and later on it was again described by him in a paper read before the Institution, and published in Vol. XX. of the Journal.

The chief objects of the inventor, namely, (1) for effecting his object without interrupting the supply; (2) for automatically indicating the completion of the charging of each set of batteries; (3) for automatically,

on such completion, changing a set of batteries from a position of being charged to one of being discharged, requiring the transposition of its connections from series to parallel and *vice versâ ;* and (4) the employment of counter electro-motive force-cells and controlling apparatus for regulating the pressure in the discharge circuit, was carried out, not only in theory but in practice, all possible conditions having been anticipated and provided for.

As with other appliances, experience showed that, as the network of distribution extended and the demand for current increased, the same ends could be secured by more simple methods.

Soon after 1892, when Mr. King was appointed to the engineering management of the Chelsea Company, while the large use of storage continued to be the chief characteristic of the system in that parish, the use of this remarkable example of Mr. King's inventive genius was discontinued.

To his ripe experience the Chelsea Company owes the design not only of their present central station in Manor Street, Chelsea (which, since his death, has been completed), but also of several of their continuous current transforming stations, in each of which are placed large batteries of accumulators, of a capacity to provide the summer daylight load, within the districts of which these sub-stations form the centre of supply.

Mr. King was elected an Associate of this Institution on the 11th of December, 1884, and was transferred to the class of Members on the 10th of January, 1889. Although he never contributed a paper, he sometimes took part in the discussions at meetings of the Institution.

C. E. W.

BENJAMIN SMITH, who died on the 9th of August, 1899, was born in 1838, at Newhaven, near Brighton. He was educated in Newhaven, and gained his earliest business experience in a bank in that town. He was next attached, first to the Electric and International Company, and then to the telegraph department of the London, Brighton, and South Coast Railway Company. Leaving this employment in 1857, he was with the Atlantic Telegraph Company until 1861, during which period he acted as an assistant electrician in the expedition which successfully laid the 1858 Atlantic cable. He afterwards joined Messrs. Glass, Elliott & Company, and obtained with them considerable experience in cable-laying. At a later date he joined the Eastern Telegraph Company, serving successively at Tripoli, Malta, Aden, Alexandria, and Bombay. In 1879 he was transferred to the Eastern and South African Company, and from 1882 until 1899 was their divisional manager at Alexandria. By his work in the decade 1870–1880 he contributed substantially to the development of duplex telegraphy as applied to submarine work, and introduced a bridge method of his own in 1876. In 1879, with the aid of his recorder-switch, he introduced a "human relay system," by which was facilitated the forwarding of messages through intermediate stations in which no electro-mechanical relay was used. He received several decorations from the Egyptian Government in recognition of his services at various times.

He was elected an Associate of this Institution on the 9th of December, 1874, and was transferred to the class of Members on the 16th of July, 1897.

FREDERICK WYLES was a native of Kent, and studied engineering work at Rochester and Chatham. Upon the recommendation of Sir William Preece, he was appointed Assistant Telegraph Engineer to the London and South-Western Railway Company in succession to Mr. A. R. M. Simkins, on October 1, 1883. For seventeen years he distinguished himself by a comprehensive thoroughness in his work, combined with an earnestness and amiability which won for him the esteem of all with whom he came in contact. The South-Western Railway Company have lost a most respected and efficient officer, who seemed destined to take a foremost position amongst railway electrical men. After an illness of a few days, he succumbed, to pneumonia following on a chill, on the 7th of May, at the age of thirty-nine years.

He was elected an Associate of this Institution on the 18th of January, 1883, and was transferred to the class of Members on the 8th of March, 1888.

C. G.

NOTICE.

1. The Institution's Library is open to members of all Scientific Bodies, and (on application to the Secretary) to the Public generally.

2. The Library is open (except from the 14th August to the 16th September) daily between the hours of 10.0 a.m. and 6.30 p.m., except on Saturdays, when it closes at 2.0 p.m.

An Index, compiled by the late Librarian, to the first ten volumes of the Journal (years 1872-81), and an Index, compiled under the direction of the late Secretary, to the second ten volumes (years 1882-91), can be had on application to the Secretary, or to Messrs. E. and F. N. Spon, 125, Strand, W.C. Price Two Shillings and Sixpence each.

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INDEX TO VOL. XXIX.

1899–1900.

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INDEX

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